

KEPCO

OPERATIONAL POWER SUPPLIES

OPS

group IX B

Model OPS 2000B

Please record the equipment nameplate
serial number in the space provided.

Serial No.

instruction manual

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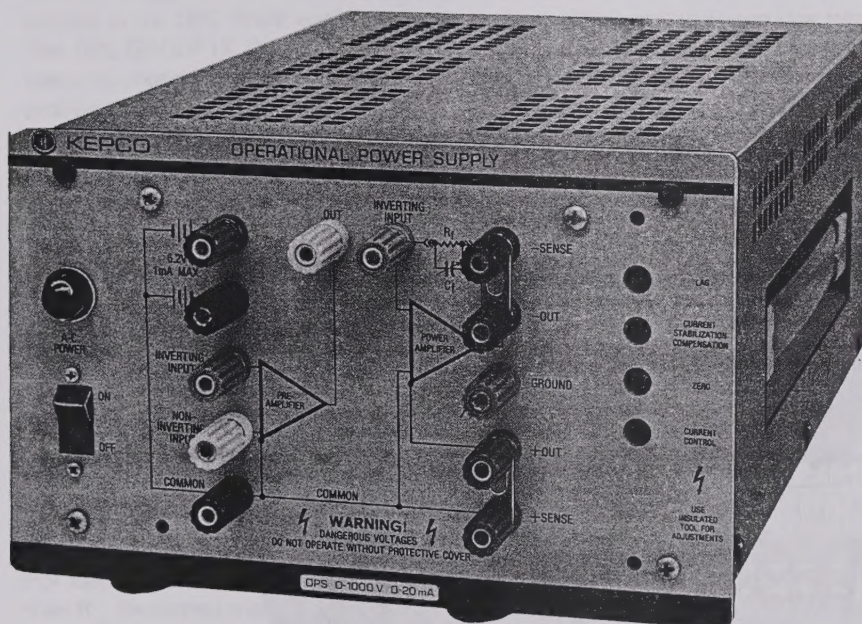


FIG. 1-1 KEPKO GROUP IX OPERATIONAL POWER SUPPLY, TYPICAL FRONT VIEW.

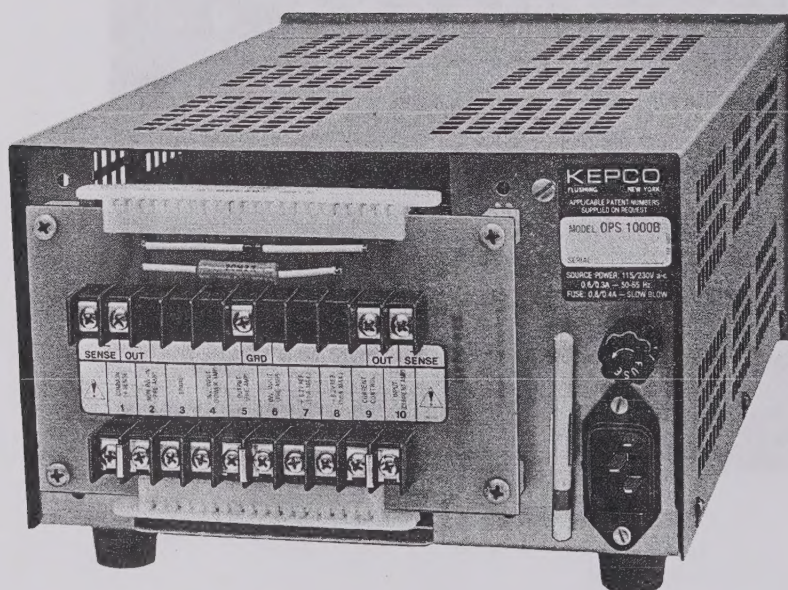


FIG. 1-2 KEPCO GROUP IX OPERATIONAL POWER SUPPLY, TYPICAL REAR VIEW.

SECTION I – INTRODUCTION

1-1 SCOPE OF MANUAL

- 1-2 This manual contains instructions for the installation, operation, and maintenance of the OPS GROUP IX Operational Power Supplies, manufactured by Kepco, Inc., Flushing, New York.

1-3 GENERAL DESCRIPTION

- 1-4 Kepco OPS GROUP IX Operational Power Supplies are a-c source powered devices which can be utilized as d-c high voltage/low current sources or, operationally programmed, as unipolar power amplifiers. Integrated circuits in the OPS "front end" contribute very low offsets and allow accurate tracking of all input signals. The OPS GROUP IX Operational Power Supplies feature sharp crossover between the voltage and current operating modes, ensuring accurate limiting over the full output current range and completely short circuit proof operation. Low output shunt capacitance permits rapid voltage programming in the voltage mode and fast load voltage recovery in the current mode of operation.
- 1-5 The OPS circuitry, in its simplest form, can be represented by one of the simplified operating diagrams in Section III of this manual. A high voltage/low current d-c source is controlled by series pass elements (vacuum tubes), which, in turn, are driven by two high gain wide-band control systems. These control systems consist of two independently programmable channels, operating into a common driver stage. The driver stage is coupled to the series pass tubes via an "exclusive OR" gate, so that only one channel is in control of the OPS output at any time.
- 1-6 Due to the high d-c gain of the control amplifiers, the OPS output characteristic approaches that of a true "autocrossover" power supply. The crossover load resistance (R_L) at any instant is given by the straight line from zero to the operating point E_O , I_O where E_O represents the OPS output voltage and I_O is the setting of the output current:

$$R_L = E_O/I_O.$$

For load resistances *greater* than R_L , the OPS voltage channel is in control, while for load resistances *smaller* than R_L the current channel is in control of the OPS output.

1-7 SPECIFICATIONS, GENERAL

- a) A-C INPUT POWER: 105 to 125V a-c *or* 210 to 250V a-c (selectable, refer to Section II), 50 to 65 Hz single phase. Approximately 75 Watts.
- b) OPERATING TEMPERATURE RANGE: (-)20°C to (+)65°C (without derating of the output).
- c) STORAGE TEMPERATURE: (-)40°C to (+)85°C.
- d) COOLING: The Kepco Operational Power Supply is designed for adequate convection cooling through the wrap-around, perforated case.
- e) ISOLATION: A maximum of 1000 volts (d-c or p-p) can be connected between chassis and either output terminal. Common-mode current from output (either side) to ground: <30 μ A rms, 300 μ A p-p at 60 Hz.
- f) OUTPUT RATINGS AND IMPEDANCES: (See Table 1-1).

MODEL	D-C OUTPUT RANGE		OUTPUT IMPEDANCE	
	VOLTS	AMPS	D-C OHMS + SERIES L VOLTAGE MODE	D-C OHMS + SHUNT C CURRENT MODE (EXT.)
OPS 500B	0-500	0-0.04	$2.2\Omega + 10\text{ mH}$	$125\text{ M}\Omega + 0.04\text{ }\mu\text{F}$
OPS 1000B	0-1000	0-0.02	$9.0\Omega + 10\text{ mH}$	$250\text{ M}\Omega + 0.02\text{ }\mu\text{F}$
OPS 2000B	0-2000	0-0.01	$34.0\Omega + 10\text{ mH}$	$500\text{ M}\Omega + 0.01\text{ }\mu\text{F}$

TABLE 1-1 OUTPUT RATINGS AND IMPEDANCES.

1-8 SPECIFICATIONS, PERFORMANCE

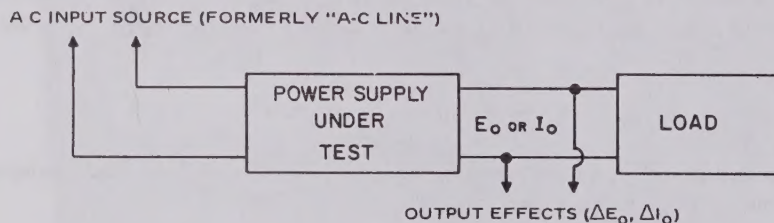
1-9 VOLTAGE CHANNEL:

- OPEN LOOP GAIN, D-C: $>1 \times 10^6$ V/V.
- D-C OFFSETS: See Table 1-2.

NOTE 1: In this instruction manual the traditional terms "line regulation" and "load regulation" are no longer used. Instead, Kepco will follow the NEMA standards for D-C Power Supplies and speak of the "Output Effects" caused by changes in the "Influence Quantities." "Output Effects" are expressed either as a percentage change, referred to the maximum specified output voltage (E_O) or current (I_O), or as an absolute change (ΔE_O , ΔI_O), directly in millivolts or milliamperes or both. The illustration below will clarify the NEMA Standard. Reference: NEMA Standard 3PY-1972.

INFLUENCE QUANTITIES

- SOURCE
- LOAD
- TEMPERATURE
- TIME



- | | | |
|-----------------------|----------------------------------|--|
| 1) DUE TO SOURCE | = SOURCE EFFECT | (formerly LINE REGULATION) |
| 2) DUE TO LOAD | = LOAD EFFECT | (formerly LOAD REGULATION) |
| 3) DUE TO TEMPERATURE | = TEMPERATURE EFFECT COEFFICIENT | ... (formerly TEMPERATURE COEFFICIENT) |
| 4) DUE TO TIME | = DRIFT | (formerly STABILITY) |

NOTE 2: The output effects for operational power supplies cannot be specified directly, since they depend on the value and quality of the external feedback components added by the user. Instead, the d-c errors are specified at the input of the OPS voltage amplifier as a change in "offset voltage" and "offset current" (ΔE_{iO} , ΔI_{iO}). To calculate the "worst case" output effects for *your* application, insert the value of the external feedback components and the specified offsets (see Table 1-2) into the ERROR EQUATION and calculate the total output effect:

$$\Delta E_O = \Delta E_{ref} (R_f/R_i) + \Delta E_{iO} (1 + R_f/R_i) + \Delta I_{iO} R_f$$

where: ΔE_O = Total Output Voltage Change
 ΔE_{ref} = Change in the Voltage Reference
 ΔE_{iO} = Change in Offset Voltage
 ΔI_{iO} = Change in Offset Current
 R_f = External Feedback Resistor
 R_i = External Input Resistor

NOTE: Variations in the value of the feedback and input resistors are considered secondary effects in the Error Equation.
See Section IV of this manual for the derivation of the Error Equation.

INFLUENCE QUANTITY	VOLTAGE CONTROL CHANNEL		CURRENT CONTROL CHANNEL OUTPUT EFFECTS	REFERENCE $\pm 6.2V \pm 5\%$ NOMINAL
	OFFSET VOLTAGE ΔE_{I_O}	OFFSET CURRENT ΔI_{I_O}		
SOURCE: 105–125V a-c	$<10 \mu V$	$<1 \text{ nA}$	$<10 \mu A$	$<0.0005\%$
LOAD: No load – full load	$<10 \mu V^{(1)}$	$<1 \text{ nA}$	$<10 \mu A$	–
TIME: 8-hour [drift]	$<20 \mu V$	$<1 \text{ nA}$	$<0.01\%$ of I_O max	$<0.005\%$
TEMPERATURE: Per $^{\circ}C$	$<20 \mu V$	$<0.5 \text{ nA}$	$<0.01\%$ of I_O max	$<0.005\%$
UNPROGRAMMED				
OUTPUT DEVIATION: ⁽³⁾ rms	$<0.01\%$ of E_O max or $35 \text{ mV}^{(2)}$		$<50 \mu A$	–
(Ripple and noise) p-p ⁽⁴⁾	$<0.1\%$ of E_O max or $150 \text{ mV}^{(2)}$		$<250 \mu A$	–

⁽¹⁾ ΔE_{I_O} for load in current stabilization mode is ΔE_O /open-loop gain. ΔE_O is the compliance voltage change.

⁽²⁾ Whichever is greater.

⁽³⁾ One terminal must be grounded or connected so that the common mode current does not flow through the load or through a current sensing resistor.

⁽⁴⁾ 20 Hz to 10 MHz.

TABLE 1-2 D-C OFFSET SPECIFICATIONS.

c) DYNAMICS:

- 1) SLEWING RATE (Fastest rate of change obtainable): >1 volt per microsecond.
- 2) PROGRAMMING TIME CONSTANT [Measured in the linear operating region, as the exponential response to an input step function. The time to reach 63% of the rated output voltage with a 1000 ohms per volt feedback resistor (R_f) and the feedback capacitor (C_f) adjusted for critical damping]. The programming time constant is approximately equal to the product " $R_f C_f$." The internal feedback capacitor (C_f) is adjustable in the range from 400 to 3900 pF
- 3) LOAD REACTANCE: Maximum capacitive loading: 0.001 microfarad. For inductive loads, series diodes in the output leads are required to protect the OPS from the back EMF generated by the load.

1-10 CURRENT CONTROL CHANNEL

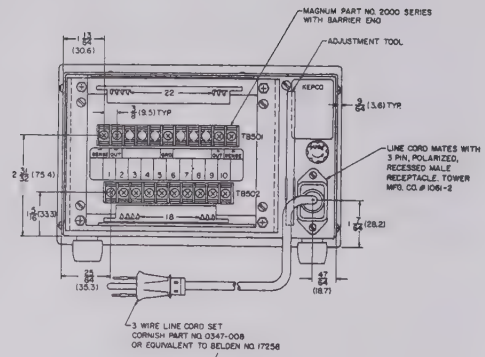
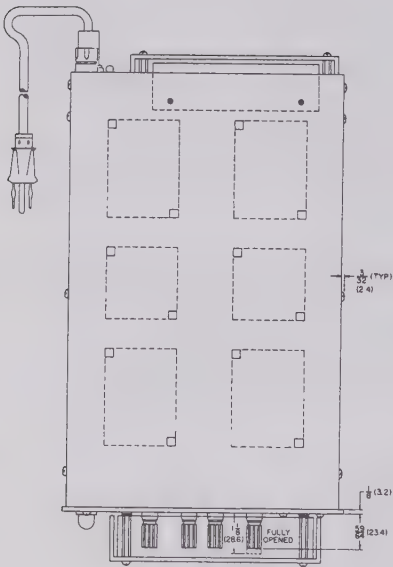
- a) OUTPUT EFFECTS: See Table 1-2.
- b) DYNAMICS: The speed with which the stabilized output current returns to the stabilization band following a step in load voltage (CURRENT RECOVERY) is either governed by the time constant of the load/feedback resistance and feedback capacitance, or by the ratio I_O/C_S (I_O = current setting, C_S = tabulated shunt capacitance, see Table 1-1), whichever is smaller.

1-11 MISCELLANEOUS FEATURES

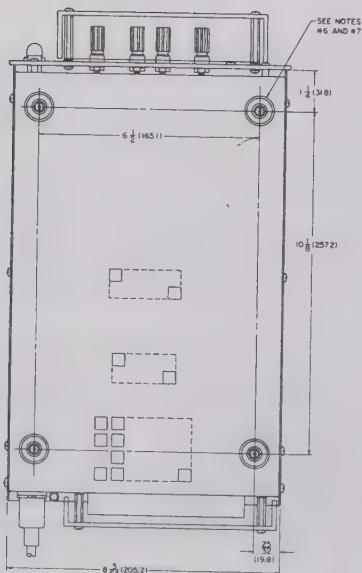
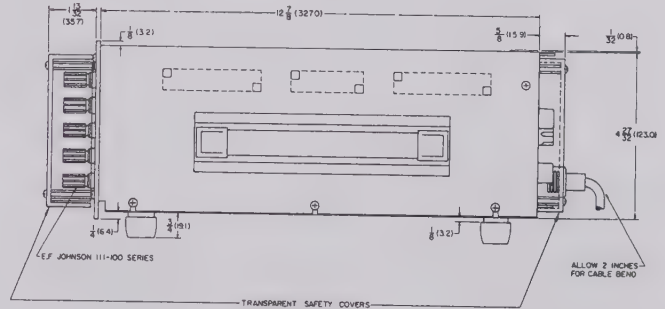
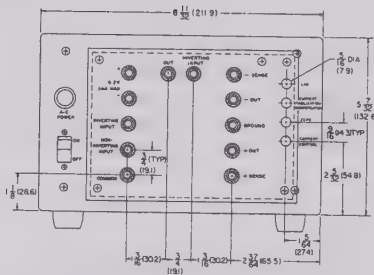
- a) VOLTAGE CHANNEL: Fixed feedback resistors (500 k ohm for OPS 500B, 1 M ohm for OPS 1000B and 2 M ohm for OPS 2000B) are connected from the (–) output/sense terminal to the null junction of the voltage mode amplifier A 0–1 milliampere control current source, connected from the (+) output/sense terminal (common) to the null junction, of the voltage mode amplifier will program the output voltage through the rated range. The control current may be derived from the built-in (+6.2V) reference, it can be provided via the preamplifier, or it can be generated from an external source, such as a function generator.
- b) UNCOMMITTED PREAMPLIFIER: The input and output terminals of a unipolar "preamplifier" are made available at the rear barrier-strip terminals. This amplifier may be used for signal processing or for passive resistance programming of the OPS voltage output.
- c) CURRENT CHANNEL: The output current is controlled by a built-in multiturn rheostat (accessible through the rear panel). The current control channel may be used as a current limiter or as a continuously adjustable d-c current source, (Specified Performance see Table 1-2). Its input is available at the rear barrier-strip terminals and may be disconnected from the internal reference source to be programmed by an external potentiometer or an external control voltage.
- d) REMOTE ERROR SENSING: Provisions are made for a 4-terminal connection to a remote load. Static voltage drops along the load wire (up to 0.5 volt per lead) can thus be illuminated.
- e) OFFSET NULLING: The initial (static) part of the voltage mode amplifier's offset (E_{I_O} , I_{I_O}) can be zeroed by a built-in multiturn trimmer.
- f) REFERENCES: A pair of nominal $\pm 6.2V$ reference voltage sources [1 mA maximum, referenced to the (+) output/sense terminal] are available at the designated terminals on the rear barrier-strip.

1-12 SPECIFICATIONS, MECHANICAL

Refer to the "Mechanical Outline Drawing," FIG. 1-2.



TERMINAL	FUNCTION
1	COMMON (+ SENSE)
2	NON INV. IN. (PRE. AMP)
3	N.C.
4	INV. INPUT (POWER AMP)
5	OUTPUT (PRE. AMP)
6	INV. INPUT (PRE. AMP)
7	+6.2 V. REF. (1mA MAX.)
8	-6.2 V. REF. (1mA MAX.)
9	CURRENT CONTROL
10	INPUT (CURRENT AMP)



- NOTES:
- THIS DRAWING IS USED FOR OPS2000, OPS2000B AND OPS2000C.
 - MATERIAL: A) CHASSIS: 16 GAUGE C.R.S. (0059) B) FRONT PANEL: 1/8" THICK ALUMINUM C) COVER: 20 GAUGE C.R.S. (0059)
 - FINISH: A) CHASSIS: CADMIUM PLATED WITH CHROMATE WASH. B) FRONT PANEL: LIGHT GREY PER FEDERAL STD 595 COLOR NO 26440 C) COVER: CHARCOAL GREY VINYL TEXTURE
 - FUSE DATA: 115 V. AC, 20A SLO BLD 230 V. AC, 0.4A SLO BLD
 - REFER TO KEPIC MANUAL FOR DETAILED SPECIFICATIONS
 - REMOVE (A) FEET FOR RACK MOUNTING
 - (A) PLASTIC MOUNTING INSERTS (UNDER FEET) FOR 8-18 THREAD CUTTING SCREWS 5/8" LONG (WITH 1/8" THICK MOUNTING PLATE)
 - DIMENSIONS WITHIN PARENTHESES ARE IN MILLIMETERS
 - TOLERANCES: A) BETWEEN MOUNTING HOLES: ±.004 (±.04) B) ALL FRONT PANEL DIMENSIONS TO MIL STD 189 C) ALL OTHER DIMENSIONS: ±.002 (±.02), EXCEPT AS NOTED

SECTION II – INSTALLATION

2-1 UNPACKING AND INSPECTION

- 2-2 This instrument has been thoroughly inspected and tested prior to packing and is ready for operation. After careful unpacking, inspect for shipping damage before attempting to operate. Perform the preliminary operational check as outlined in par. 2-11 below. If any indication of damage is found, file an immediate claim with the responsible transport service.

2-3 TERMINATIONS

- FRONT PANEL: Refer to FIG. 2-1.
- REAR: Refer to FIG. 2-2.

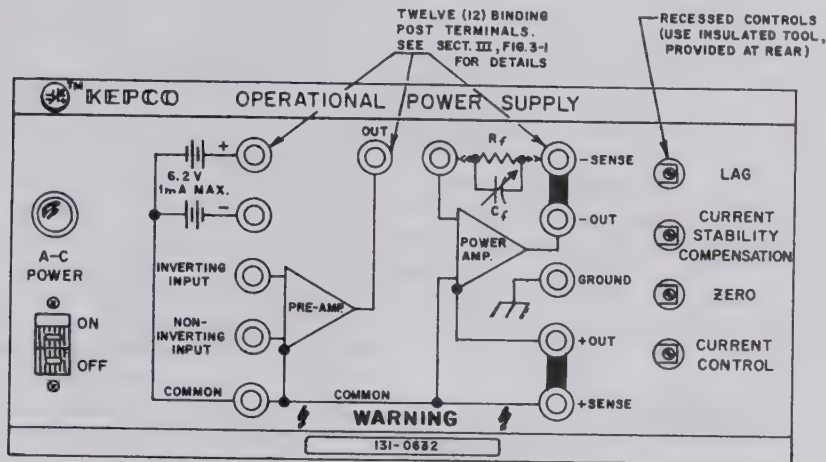


FIG. 2-1 FRONT PANEL, OPS GROUP IX MODELS.

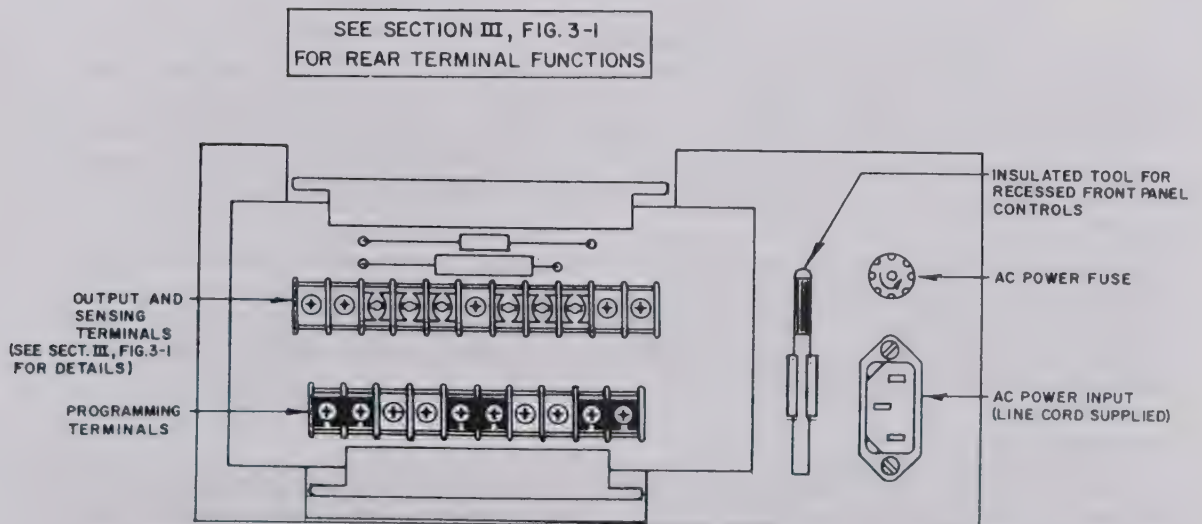


FIG. 2-2 REAR TERMINATIONS, OPS GROUP IX MODELS.

2-4 A-C POWER REQUIREMENTS

- 2-5 The Kepco OPS Power Supply is normally delivered for operation on a single phase, 105 to 125V a-c source, 50 to 65Hz. For operation on 210 to 250V sources the jumper connections on the main transformer (T201), as well as the power fuse value, must be changed as shown in FIG. 2-3.

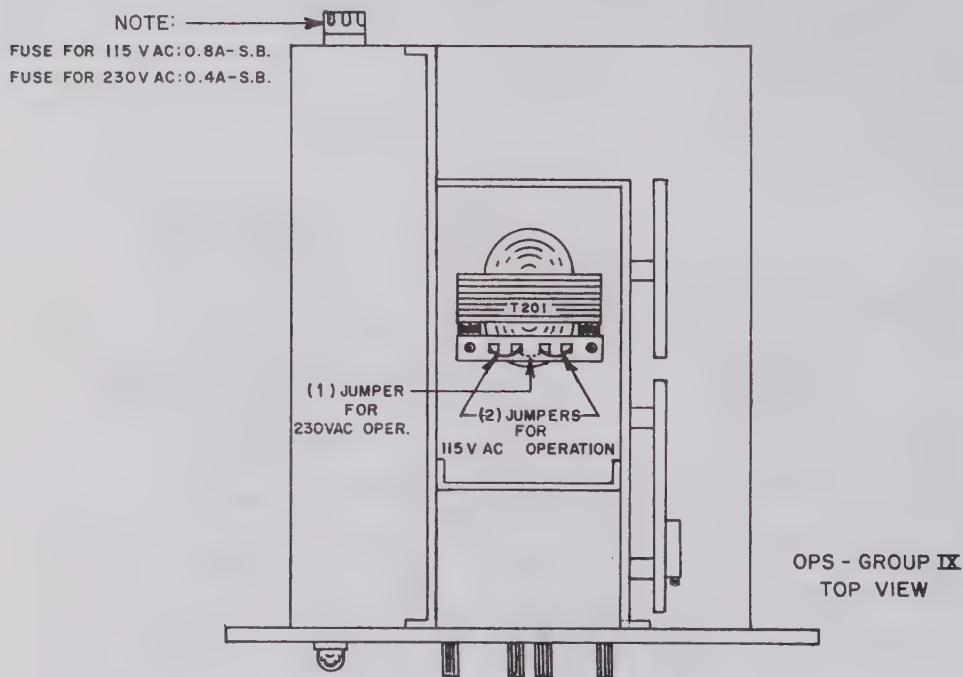


FIG. 2-3 TRANSFORMER CONNECTIONS FOR 115V A-C AND 230V A-C OPERATION.

2-6 GROUNDING

WARNING

- 2-7 **A-C SAFETY GROUND.** THE DANGEROUS VOLTAGES PRESENT IN THIS EQUIPMENT MAKE IT IMPERATIVE THAT THE CASE IS KEPT AT GROUND POTENTIAL AT ALL TIMES. If the 3-wire line cord with 3-prong safety plug (supplied with this equipment) is used in combination with a properly grounded outlet, this is taken care of automatically. If an adapter for a nongrounded outlet is used, however, the case must be grounded separately. A separate "GROUND" terminal is provided for this purpose on the rear of the OPS. (See FIG. 2-4.)
- 2-8 **D-C SIGNAL GROUND.** It is good practice to ground one side of the output at all times. Where the circuit requirements do not permit grounding of the output, additional precautions against dangerous electrical shocks must be taken. Equipment used in conjunction with high voltage operational power supplies must be able to withstand the operating voltage of the latter. Properly insulated wires are essential. Refer also to Section III par. 3-3c for more signal grounding details.
- 2-9 **COOLING**
- 2-10 The Kepco Operational Power Supply is designed for adequate convection cooling through the wrap-around perforated case under specified operating conditions. **Sufficient space around the unit must be allowed for free air circulation.** If the instrument must be mounted into confined spaces, forced air cooling may be necessary to keep the surrounding air within the specified ambient temperature limits.

2-11 FUNCTIONAL CHECK

- 2-12 A simple operating check, after unpacking and before permanent installation, is advisable to ascertain whether the OPS has suffered damage resulting from shipment. Refer to FIG. 2-1 and FIG. 2-2 for the location of the operating controls and the rear terminals.

WARNING

THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:

- 1) REMOVE A-C INPUT POWER FROM THE OPS BEFORE REMOVING THE PROTECTIVE FRONT OR REAR COVER. EXERCISE EXTREME CARE IN MAKING ALL CONNECTIONS TO AND FROM THE FRONT AND REAR TERMINALS.
- 2) WIRES AND/OR CABLES, CONNECTED FROM THE OPS TERMINALS TO EXTERNAL COMPONENTS OR PROGRAMMING DEVICES MUST BE PROPERLY INSULATED AND SECURELY TERMINATED ON BOTH ENDS, TO MAKE ACCIDENTAL TOUCH IMPOSSIBLE. REINSTALL FRONT OR REAR PROTECTIVE TERMINAL COVER AFTER ALL CONNECTIONS TO THE OPS HAVE BEEN COMPLETED.
- 3) ***THE OPS CHASSIS AND COVER MUST BE SAFETY-GROUNDED TO A RELIABLE A-C SOURCE GROUND.*** A SAFETY-GROUND MAY BE ESTABLISHED BY USING A GROUNDED A-C POWER OUTLET OR, IF THE LATTER IS NOT AVAILABLE, BY MEANS OF A SEPARATE WIRE, FROM THE PROVIDED "GROUND" TERMINAL TO A RELIABLE A-C SOURCE GROUND POINT.
- 4) ***EITHER THE POSITIVE, OR THE NEGATIVE OUTPUT TERMINAL OF THE OPS SHOULD BE SIGNAL GROUNDED.*** IF FOR ANY REASON, GROUNDING OF THE OUTPUT IS NOT POSSIBLE, ADDITIONAL PRECAUTIONS MUST BE TAKEN TO MAKE ANY ACCESS TO THE ISOLATED OUTPUT IMPOSSIBLE. ***EXTERNAL INPUT SOURCES MUST BE ISOLATED FROM THE A-C POWER SOURCE FOR A MINIMUM OF 2000 VOLTS,*** IF THE NEGATIVE OUTPUT IS GROUNDED.
- 5) ***FOR ANY CONTROL ADJUSTMENTS ON THE OPS USE ONLY THE INSULATED TOOL WHICH IS ATTACHED AT THE REAR.***

2-13 PROCEDURE, FUNCTIONAL CHECK (Refer to FIG. 2-4)

- 1) Without connecting the OPS to the power line, open the protective rear terminal cover.
- 2) Remove jumpers (1)–(2) on the REAR PROGRAMMING TERMINALS and connect wires to terminals (1), (2), and (7). Connect two (2) wires to the REAR OUTPUT TERMINALS (– out) and (+ out). NOTE: THESE TWO WIRES MUST BE HIGH VOLTAGE WIRES WITH AN INSULATION RATING OF AT LEAST 2 k VOLTS.
- 3) Reinstall the protective rear terminal cover.
- 4) Connect a 5 k ohm potentiometer in series with a 1.5 k ohm fixed resistor to the REAR PROGRAMMING TERMINALS (1), (2), (7) as shown in FIG. 2-4. Connect a fixed resistor (5 k ohm) between terminals (4) and (5). Connect a suitable voltmeter to the REAR OUTPUT TERMINALS as shown in FIG. 2-4. MAKE THE GROUND CONNECTIONS AS SHOWN IN FIG. 2-4.
- 5) Connect the OPS to a grounded a-c power outlet. Turn the connected VOLTAGE CONTROL potentiometer to the position of zero resistance between terminals (1) and (2) as shown in FIG. 2-4.
- 6) Turn OPS A-C POWER SWITCH "on." The OPS uses vacuum tubes as the series pass element. Before full output is available, a warm-up delay of about 25 seconds after turn-on is provided to allow the vacuum tube cathodes to reach proper operating temperature. Observe the voltmeter at the output and turn the VOLTAGE CONTROL potentiometer clockwise. The output voltage of the OPS should increase smoothly from zero to the maximum rated d-c output voltage, as the VOLTAGE CONTROL is turned through its range. Turn VOLTAGE CONTROL to zero output volts again and turn OPS A-C POWER SWITCH "off."

NOTE: THE FUNCTIONAL CHECK MAY BE PERFORMED BY CONNECTING TO THE FRONT PANEL BINDING POSTS INSTEAD OF THE REAR TERMINALS. SEE SECTION III, FIG. 3-1.

- 7) Replace the voltmeter at the output with a suitable milliammeter. LEAVE ALL OTHER COMPONENTS CONNECTED AS BEFORE.
- 8) Turn OPS a-c power switch "on." Allow for approximately 25 seconds warm-up. Turn VOLTAGE CONTROL clockwise, sufficiently to produce maximum output current, as evident on the ammeter across the output.
- 9) LOCATE THE " I_O CONTROL" (accessible *through* the protective front terminal cover) and turn slowly counterclockwise. Observe the milliammeter across the output. The OPS output current should smoothly change from the maximum rated value to approximately zero as the I_O CONTROL is turned through its range. Return the setting of the I_O CONTROL to its previously set value (I_O max rated) or to any intermediate value desired.
- 10) This concludes the functional check of the OPS. Turn A-C POWER SWITCH "off," and remove external components and metering.

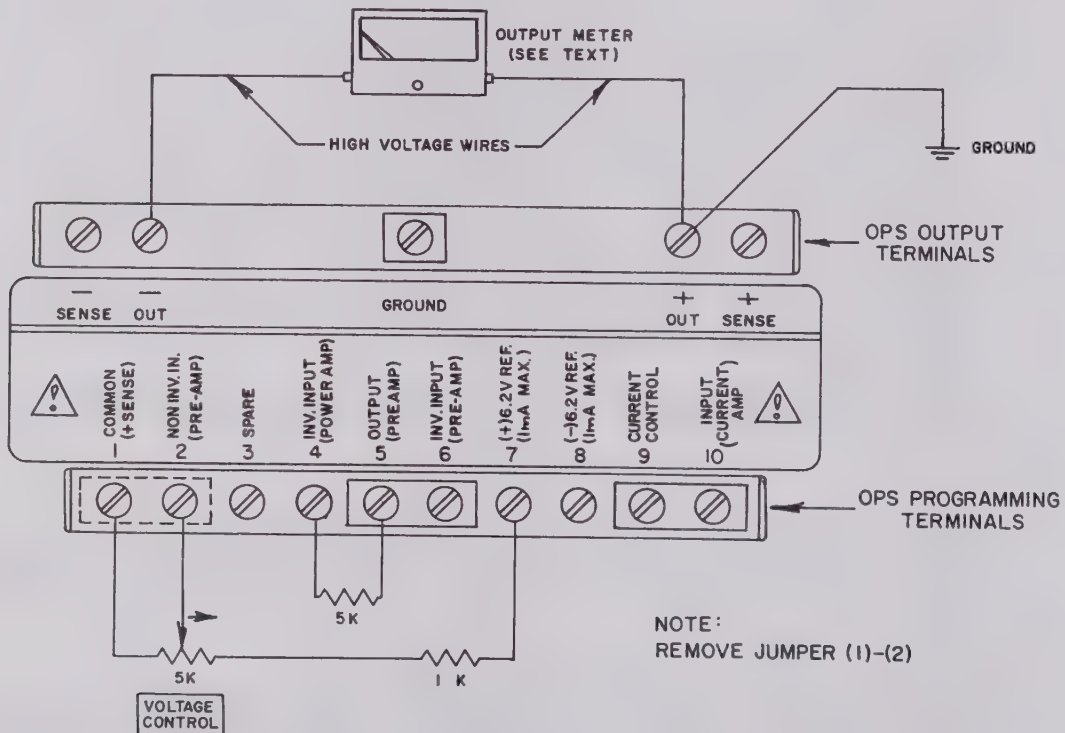


FIG. 2-4 TEST SET-UP FOR FUNCTIONAL CHECK OF THE OPS.

2-14 INSTALLATION (See "Mechanical Outline Drawing," Section I, FIG. 1-2)

- 2-15 OPS GROUP IX models can be operated directly on the bench, or they can be rack-mounted, using either the Kepco RA-24 (mounts two OPS GROUP IX models), or the Kepco RA-32 (mounts one OPS GROUP IX model and three 1/6 rack width Kepco Modular Supplies) hardware systems. For rack-mounting the four bottom feet of the OPS must be removed.

2-16 LOAD CONNECTION (See also Section III, par. 3-3 a, b)

2-17 The load may be connected in either one of the ways illustrated in FIG. 2-5. IMPORTANT NOTE: IF ERROR SENSING IS USED, THE SHORTING LINKS BETWEEN OUTPUT AND SENSING TERMINALS MUST BE COMPLETELY REMOVED. IF ERROR SENSING IS NOT USED, THE LINKS MUST BE CONNECTED AT THE FRONT IF THE LOAD IS AT THE FRONT AND THE LINKS MUST BE CONNECTED AT THE REAR, IF THE LOAD IS AT THE REAR.

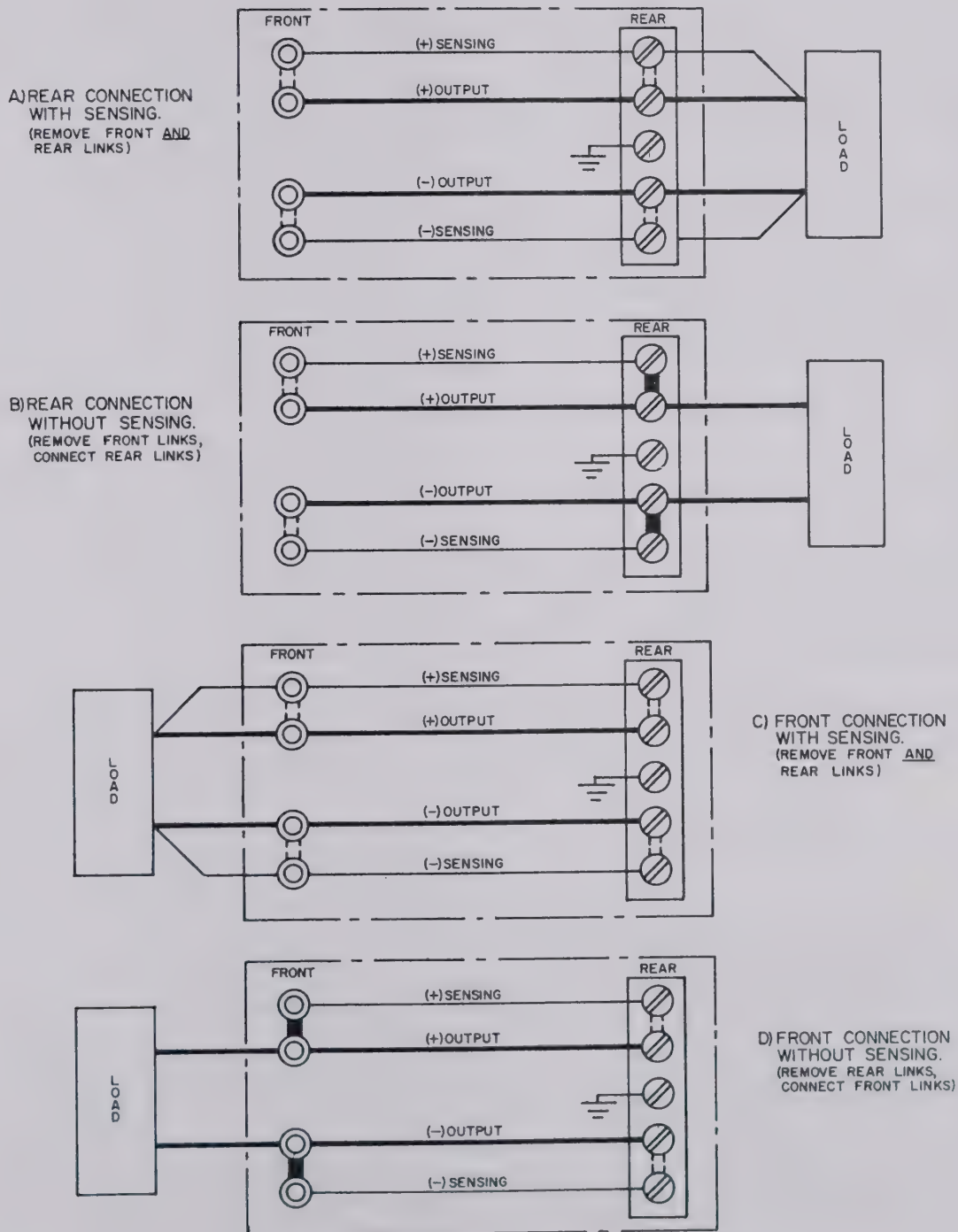


FIG. 2-5 LOAD CONNECTIONS, OPS GROUP IX.

SECTION III — OPERATION

3-1 INTRODUCTION

3-2 Kepco OPS GROUP IX and X Operational Power Supplies are two-channel, multifunction instruments which can be used in a variety of operating modes:

- a) As a PRECISION, HIGH SPEED VOLTAGE SOURCE, the voltage control channel of the OPS is used to control the output either manually by means of an external potentiometer or a control voltage, or automatically, by means of digital input signals, using a Kepco SN Digital Programmer. Examples for some of these applications are given in FIGS. 3-4 and 3-7. The current control channel of the OPS serves as a "current limiter" in these examples.
- b) As a UNIPOLAR WIDE-BAND VOLTAGE AMPLIFIER, the voltage channel of the OPS is used to amplify input signals to the maximum rated OPS output voltage. The current control channel of the OPS serves as a "current limiter" (see FIG. 3-12 for example).
- c) The current control channel of the OPS may (independently of the voltage control channel) be programmed to provide a remote controlled current limit function. The current control channel may also be used to operate the OPS as a CONTINUOUSLY ADJUSTABLE CONSTANT CURRENT SOURCE, while the voltage channel is committed as a voltage limiter. Examples for these applications are illustrated in FIGS. 3-13 and 3-14.
- d) The OPS voltage channel may be used for the precision control and stabilization of the output current in the microampere range. The control voltage may be derived from the OPS reference source, or from an external source. See FIGS. 3-16, 3-18.

3-3 Detailed description of these and other operating modes will be given in the following paragraphs. BEFORE ACTUAL OPERATION, however, the following important general comments on power supply programming should be considered:

- a) LOAD CONNECTION (I). The basic interconnection between the OPS and the load are shown in FIG. 3-1. The load wire size for the 2-wire connection shown should be as large as practicable to keep the series resistance and inductance low. In addition, the load wire pair should be tightly twisted, to reduce possible "pick-up" from stray magnetic fields. The basic 2-wire connection is useful where the voltage drop in the load wires is of minor consequence, as for example, operation into a constant load or in a constant current operating mode.
- b) LOAD CONNECTION (II). The recommended load connection for all applications requiring minimum load effect across a *remote* load is shown in FIG. 3-4. A twisted, shielded pair of wires (No. 20 AWG minimum) are connected from the OPS "± sensing" terminals to the load. This "remote error sensing" technique will compensate for load wire voltage drops up to 0.5 volts per wire.

NOTE: OBSERVE POLARITIES:

THE **NEGATIVE** SENSING WIRE MUST GO TO THE **NEGATIVE** LOAD WIRE.

THE **POSITIVE** SENSING WIRE MUST GO TO THE **POSITIVE** LOAD WIRE.

- c) GROUNDING

- 1) A-C (SAFETY) GROUND (See Section II, par. 2-6).
- 2) D-C (SIGNAL) GROUND. Specified ripple and noise figures for operational power supplies are valid *only* with one side of the output/load circuit returned to a common ground point (refer to Section I, Table 1-2). The *positive* side of the OPS output is shown grounded in all application diagrams, since it is "common" to both, internal reference source and any external signal input source. If the application requires, the *negative* side of the OPS output may be signal-grounded or the OPS output may be left ungrounded (floating). In the latter case, however, the ripple and noise level will increase somewhat, since the common-mode current (specified in Section I, par. 1-7g) flows now through the load (Voltage Mode) or through the external sensing resistor (Current Mode). The signal ground point in the OPS/load circuit must consist of a *single point* only, to which all input source grounds, shields and load grounds are connected. Multiple signal grounds in the OPS output/load circuit cause "ground-loop" problems, since noise signals develop across the impedances between the multiple ground points. The exact physical location of the "best" single ground point must be carefully selected for minimum ripple/noise output.

- d) DIAGRAMS. Application and test setup diagrams on the following pages show the symbolic and simplified representation of the OPS GROUPS IX and X Power Supply Circuit. The terminal numbers shown in these diagrams correspond with the actual terminal numbers on the two barrier-strips located at the rear of the OPS (refer to FIG. 3-1) NOTE: GROUP IX OPS MODELS HAVE FRONT PANEL TERMINALS, DUPLICATING MOST OF THE REAR TERMINAL FUNCTIONS (SEE FIG. 3-1). THE FRONT PANEL TERMINALS ARE NOT SHOWN IN SUBSEQUENT DIAGRAMS IN THIS SECTION

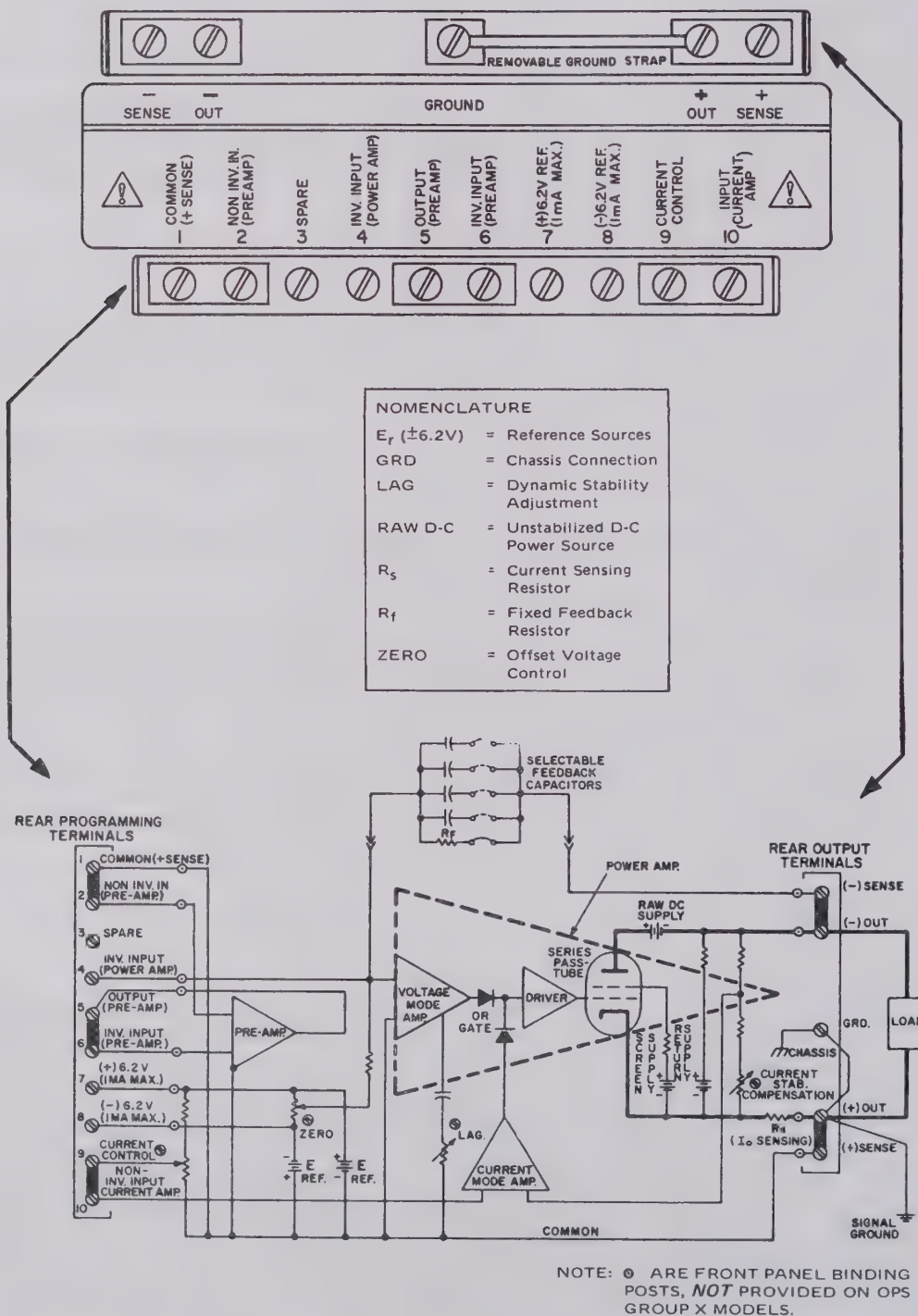


FIG. 3-1 ACTUAL OPS REAR TERMINATIONS (TOP) AND SIMPLIFIED SCHEMATIC DIAGRAM (BELOW)

- e) **EXTERNAL PROGRAMMING RESISTORS.** External programming resistors should be high-quality units, with low-temperature coefficients. Resistors should be selected carefully, since in most applications, the limitations for stability and drift are due, not to the OPS, but to the programming resistors. Selection criteria for resistors are (in order of importance):
- 1) TEMPERATURE COEFFICIENT
 - 2) LEAKAGE (IN VALUES ABOVE 100 k OHM)
 - 3) HUMIDITY EFFECTS
 - 4) DRIFT WITH TIME
 - 5) SELF-HEATING
 - 6) TOLERANCE
- For variable resistors (potentiometers or rheostats) similar selection criteria apply. In addition, such specifications as listed below should be carefully considered if the application requires:
- 1) END RESISTANCE
 - 2) LINEARITY
 - 3) CAPACITIVE AND INDUCTIVE EFFECTS
- f) **ACTIVE PROGRAMMING SOURCES.** External programming sources (Signal Generators, etc.) or reference sources should have temperature coefficients and drift specifications comparable to (or better than) the OPS Power Supply. **CAUTION:** A-C source-operated programming sources must have their output isolated from the case. Older signal generators which do not have isolated outputs, can only be used if their *negative* output is tied to the case and can be connected to the OPS "common."
- g) **EXTERNAL SWITCHES.** Switching devices, used for step-voltage or current programming of the OPS, should be of the "make before break" type.
- h) **EXTERNAL LEADS.** Shielded (preferably twisted) lead pairs are recommended for all input connections to the OPS control channels. The shield should be connected (single-ended) to the chosen signal ground point. Shielded leads should be held as short as practicable. Output leads must be "high voltage" wire, rated at least for the maximum OPS output voltage.

WARNING

THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:

- 1) EXERCISE EXTREME CARE IN MAKING ALL CONNECTIONS TO AND FROM THE OPS TERMINALS. ***REMOVE A-C POWER FROM THE OPS BEFORE MAKING ANY CONNECTIONS!***
- 2) AN INTERLOCK DEVICE REMOVES THE A-C SOURCE POWER FROM THE OPS IF THE TERMINAL COVER PLATE IS LIFTED, OR IF THE MAIN COVER IS REMOVED. ***DO NOT BYPASS THE INTERLOCK!*** (OPS GROUP X ONLY.)
- 3) WIRES AND/OR CABLES, CONNECTED FROM THE OPS TERMINALS TO EXTERNAL COMPONENTS OR PROGRAMMING DEVICES MUST BE PROPERLY INSULATED AND SECURELY TERMINATED ON BOTH SIDES, TO MAKE ACCIDENTAL TOUCH IMPOSSIBLE. FEED-THROUGH HOLES ARE PROVIDED ON THE OPS PROTECTIVE COVER, TO BRING THE WIRES FROM THE OPS REAR TERMINALS TO THE OUTSIDE.
- 4) ***THE OPS CHASSIS AND COVER MUST BE SAFETY-GROUNDED TO A RELIABLE A-C SOURCE GROUND.*** A SAFETY-GROUND MAY BE ESTABLISHED BY USING A GROUNDED A-C POWER OUTLET OR, IF THE LATTER IS NOT AVAILABLE, BY MEANS OF A SEPARATE WIRE, FROM THE PROVIDED "GROUND" TERMINAL TO A RELIABLE A-C SOURCE GROUND POINT.
- 5) ***EITHER THE POSITIVE, OR THE NEGATIVE OUTPUT TERMINAL OF THE OPS SHOULD BE SIGNAL GROUNDED.*** IF FOR ANY REASON, GROUNDING OF THE OUTPUT IS NOT POSSIBLE, ADDITIONAL PRECAUTIONS MUST BE TAKEN TO MAKE ANY ACCESS TO THE ISOLATED OUTPUT IMPOSSIBLE. ***EXTERNAL PROGRAMMING SOURCES MUST BE ISOLATED FROM THE A-C POWER SOURCE FOR A MINIMUM OF 5000 VOLTS,*** IF THE NEGATIVE OUTPUT IS GROUNDED.
- 6) ***FOR ALL CONTROL ADJUSTMENTS ON THE OPS USE ONLY THE INSULATED TOOL WHICH IS ATTACHED AT THE REAR.***

THE OPS AS A HIGH SPEED, PRECISION VOLTAGE SOURCE

3-4 OUTPUT VOLTAGE CONTROL, USING AN EXTERNAL CONTROL VOLTAGE

3-5 GENERAL. The output voltage of the OPS can be controlled by means of an external d-c control voltage. This can be accomplished in two ways, either by addressing the POWER AMPLIFIER input directly, or by applying the control voltage via the PREAMPLIFIER. The method best suited to *your* application will mainly depend on the available control voltage source.

3-6 DIRECT VOLTAGE PROGRAMMING. This control method is suitable for control voltage sources which, for the full OPS output voltage and with the built-in fixed feedback resistor, are able to supply at least 1 milliampere of control current via the series input resistor to the INVERTING INPUT of the POWER AMPLIFIER. (See FIG. 3-2.)

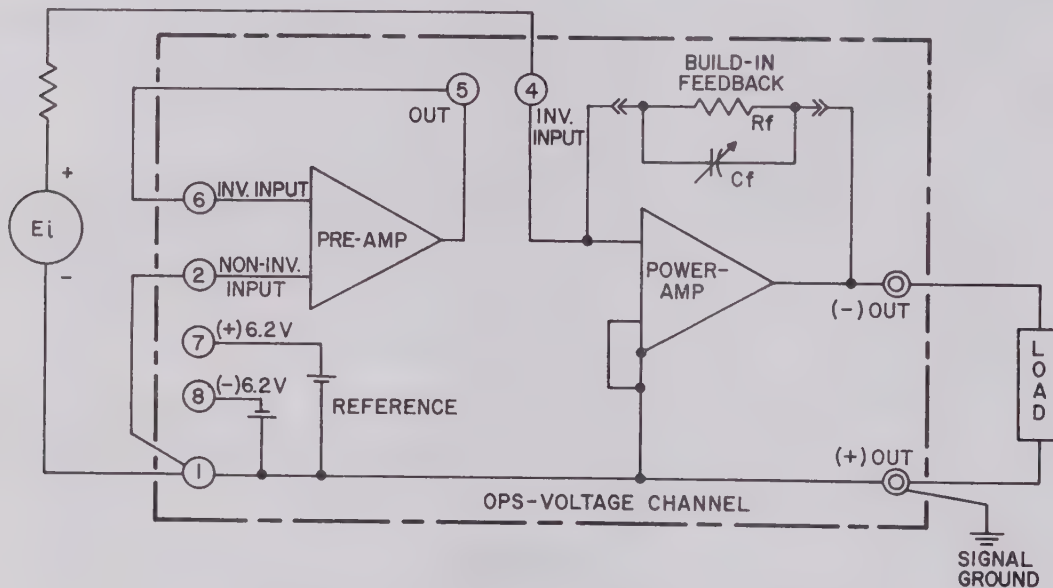


FIG. 3-2 EQUIVALENT DIAGRAM, OPS VOLTAGE CONTROL CHANNEL CONNECTED FOR DIRECT VOLTAGE PROGRAMMING.

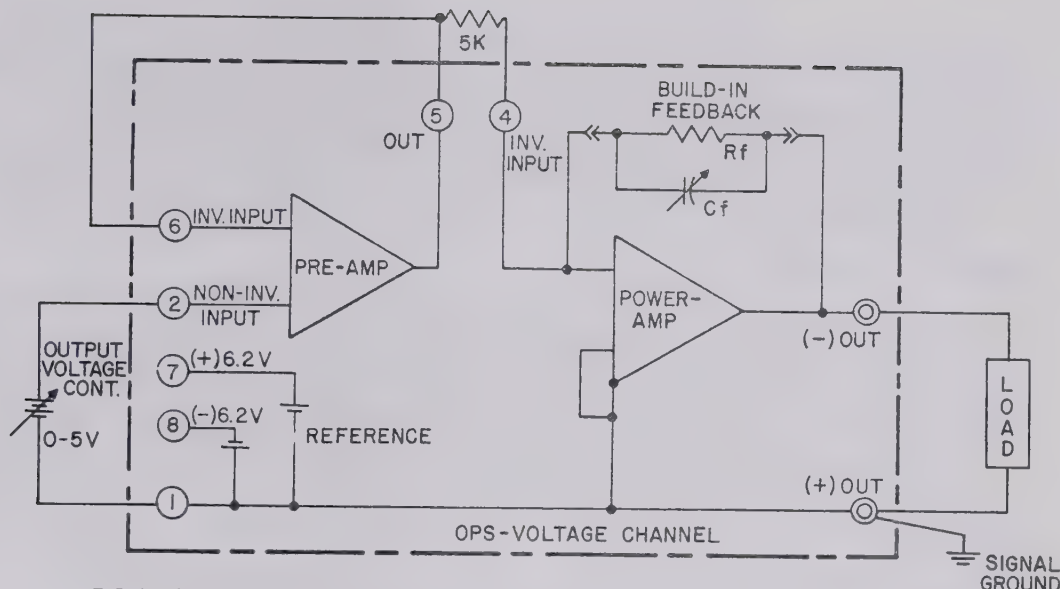
3-7 The OPS voltage control channel is used here as an inverting power amplifier. The output equation for this programming method can be expressed by:

$$E_o = E_i \left(\frac{R_f}{R_i} \right), \text{ (Eq. 1), where: } \begin{array}{ll} E_o & = \text{OPS Output Voltage} \\ E_i & = \text{External Control Voltage} \\ R_f & = \text{OPS (Fixed) Feedback Resistor} \\ R_i & = \text{External Input Resistor} \end{array}$$

3-8 The ratio of the internal (fixed) feedback and external input resistor (R_f/R_i) represents the (fixed) closed-loop gain of the OPS. If, for example, R_i is chosen to be 5 k ohms, the closed-loop gain is dimensioned for each OPS model such that a 0–5 volt control voltage (E_i) presented to the inverting input of the POWER AMPLIFIER will produce the full output voltage range.

3-9 The input source (0–5 volts at 1 mA) must be UNIPOLAR (vary in one direction only) and POSITIVE with respect to the COMMON terminal (see par. 3-36 and par. 3-42 for control methods with NEGATIVE and BIPOLAR input sources).

3-10 VOLTAGE PROGRAMMING VIA THE PREAMPLIFIER. Since, in this control method, the external control voltage is connected to the noninverting input of the PREAMPLIFIER, the input impedance is very high. The external control voltage source, therefore, has to supply only the small preamplifier bias current (in the nanoampere range). The PREAMPLIFIER is connected (by means of strapping of the PROGRAMMING TERMINALS) as a "voltage repeater" and its output is connected to the inverting input of the POWER AMPLIFIER. (See FIG. 3-3.)



- 3-11 As shown in FIG. 3-3, the PREAMPLIFIER output supplies the required 1 milliampere control current via the series input resistor (R_i) to the inverting input of the POWER AMPLIFIER, which responds as expressed by equation (1). A 0–5 volt control voltage and a 5 k ohm input resistor (R_i) will, therefore, control the OPS output voltage over its full range.
- 3-12 The uncommitted PREAMPLIFIER of the OPS has both inputs and its output terminated on the PROGRAMMING terminals. It can, therefore, be used for a variety of other tasks. If, for example, the input voltage source is *negative*, the PREAMPLIFIER can be connected in an inverting configuration and thus supply the control signal to the POWER AMPLIFIER input. (See par. 3-30 and 3-36 for other PREAMPLIFIER applications.)

- 3-13 VOLTAGE PROGRAMMING, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)
- 1) Connect the input source (E_i), load and output voltmeter (M1) to the OPS as shown in FIG. 3-4. FOR INTERCONNECTION DETAILS AND SAFETY PRECAUTIONS, TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.
 - 2) Turn OPS "on." Set input source (E_i) to "zero" and turn "on."
 - 3) Adjust input source from "zero" to 5 volts. The OPS output should vary smoothly from zero to its maximum rated output voltage. Return input source to "zero."

3-14 CALIBRATION (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) Check output voltmeter (M1) for zero reading and correct by adjusting the OPS ZERO control.
- 2) Set input source (E_i) to exactly 5 volts. Observe output voltmeter (M1). Calibrate the input source so that the exact value of the maximum rated OPS output voltage is read out on M1.
- 3) Set input source (E_i) to "zero" again, recheck the calibrated zero point and correct with the OPS ZERO control if necessary.

3-15 DYNAMIC ADJUSTMENTS

3-16 The wide-band characteristic of the OPS may give rise to dynamic instability ("ringing," "overshoot," "oscillations," etc.) at the output, especially with input sources producing a step-function and/or where the output is loaded with excessive capacitance. In the OPS, provisions have been made to stabilize the voltage channel amplifier for a fairly wide range of load conditions. A feedback capacitor "strapping arrangement" is provided on a printed circuit board (accessible after cover removal) and an adjustable lag network can be controlled through the OPS protective rear cover (OPS GROUP X) or through the front panel (OPS GROUP IX). The response characteristics of the OPS output are adjusted at the factory by optimizing the OPS square wave response at full power output (see FIG. 3-5). In cases of dynamic instability in *your* application, select the feedback capacitor and adjust the lag network as described in the following paragraph.

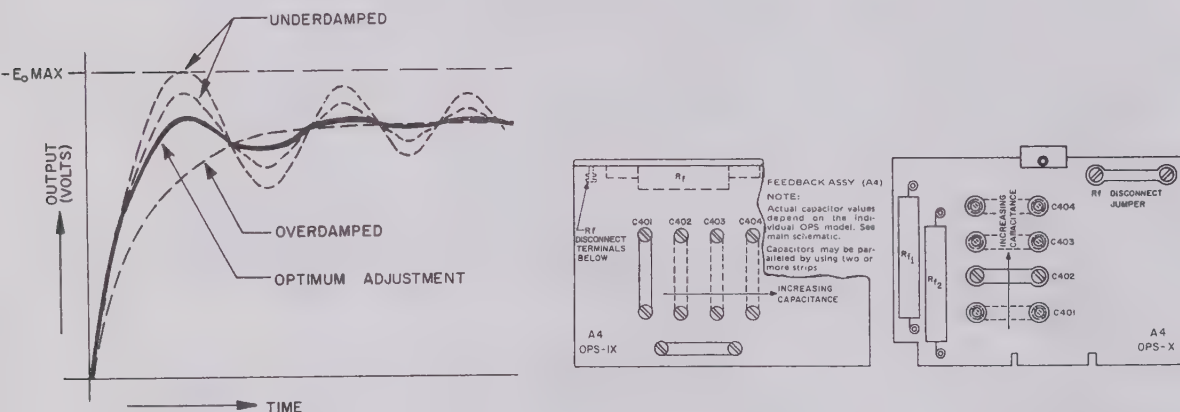


FIG. 3-5 OUTPUT RESPONSE TO A SQUARE WAVE AND FEEDBACK CAPACITOR LOCATION.

3-17 DYNAMIC ADJUSTMENTS, PROCEDURE

- 1) With the OPS set up with the chosen operating conditions and working into the designated load, observe the output with a suitable oscilloscope for evidence of dynamic instability.
- 2) If instability is present, remove a-c power from the OPS. Remove the OPS cover and increase the feedback capacitance by changing the jumper link on the auxiliary board (A4- see FIG. 3-5) to the desired position. Re-install cover and turn OPS "on" again.
- 3) Re-check operation and correct persistent instability by adjusting the OPS LAG control until stable operation is achieved.
- 4) NOTE: Persistent instability may be caused by excessive capacitive loading. (Maximum capacitive load for the OPS is specified as 0.001 μ F.)

3-18 OUTPUT CURRENT ADJUSTMENT

3-19 The OPS Power Supply is equipped with a continuously adjustable output current control, which is factory adjusted for the maximum rated output current. The control is mounted recessed from the rear protective cover (OPS GROUP X) or from the front panel (OPS GROUP IX) and marked I_o CONTROL. The setting of the I_o CONTROL determines the output current limit point of the OPS, when the voltage channel is in control of the output. If the ratio of the output voltage setting to load resistance (E_o/R_L) is *greater* than the output current value of the I_o CONTROL setting, the current channel takes control and the OPS transfers from the "voltage" to the "current" control mode. In this mode, the OPS stabilizes the output current, reducing the load voltage proportional to the load resistance thus providing complete short circuit protection. The output current control may be set between 2% and 110% of the rated OPS output current range by following the procedure described below.

3-20 OUTPUT CURRENT ADJUSTMENT, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) Retain the basic programming circuit shown in FIG. 3-4, but replace the LOAD and the PRECISION VOLTMETER (M1) by a suitable ammeter. Turn OPS "on".
- 2) Observe the ammeter across the OPS output and adjust I_O CONTROL until the desired output current is read out on the ammeter.
- 3) Turn OPS "off," disconnect ammeter and reconnect the LOAD. This concludes the output current adjustment.

3-21 OUTPUT CURRENT COMPENSATION ADJUSTMENT

3-22 The fixed feedback resistance of the OPS constitutes an internal shunt load in the current mode of operation. The shunt current thus flowing through the feedback resistance, if not compensated, produces an error proportional to the ratio of the feedback and the load resistance. The compensating circuit, provided in the OPS, is factory adjusted for best current stabilization with the built-in feedback resistor (R_f). If other feedback resistors are used, the compensating circuit may be readjusted for optimum output current stabilization using the test set-up shown in FIG. 3-6 and following the procedure described below.

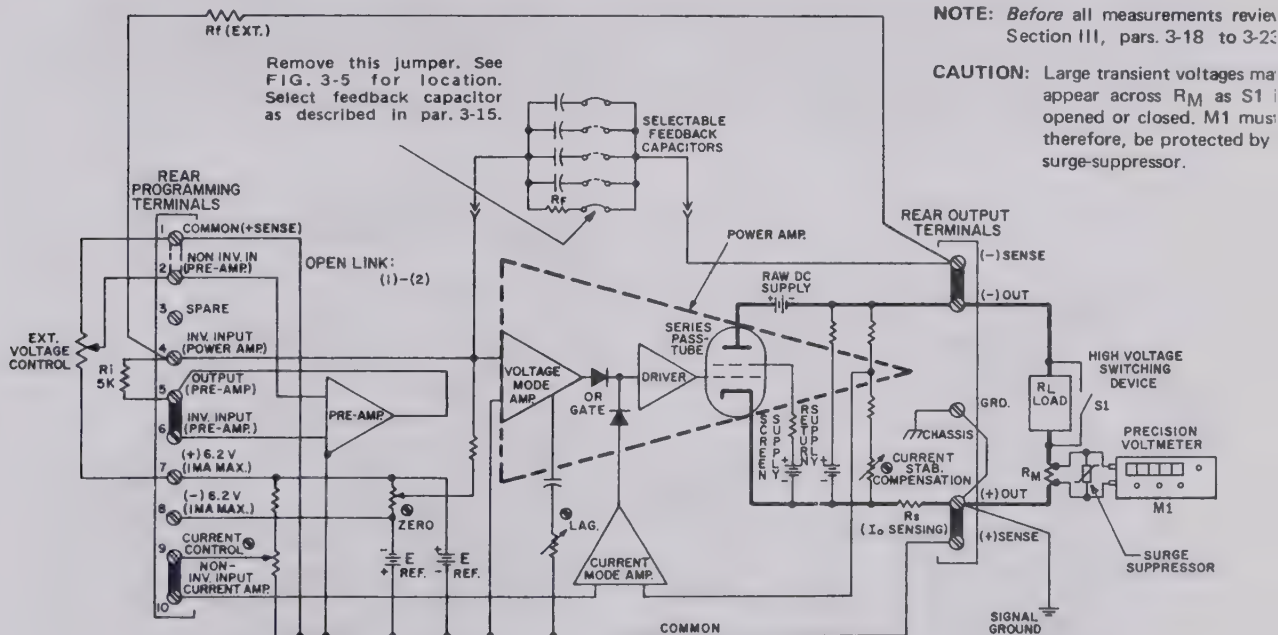


FIG. 3-6 TEST SET-UP FOR COMPENSATION ADJUSTMENT AND OUTPUT CURRENT STABILITY MEASUREMENTS.

3-23 OUTPUT CURRENT COMPENSATION ADJUSTMENT, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) Set up the test circuit shown in FIG. 3-6. Select R_L as required and let $R_M \approx 1 \text{ k ohm}$. Follow the turn-on procedure as described in par. 3-13. Set required compliance (load voltage) with the EXT. VOLTAGE CONTROL.
- 2) Read and record the voltage drop (V_{RM}) across the measuring resistor (R_M). Close S1 and note the **change** in the voltage drop (ΔV_{RM}) across R_M . Current stability as a **percentage** can be expressed by: $\Delta V_{RM}/V_{RM} \times 100\%$.
- 3) Locate the CURRENT COMPENSATION CONTROL and adjust by observing the output meter (M1) while opening and closing the load switch (S1). Adjust for minimum **change** (ΔV_{RM} MINIMUM) across the measuring resistor (R_M).
- 4) Turn OPS "off," remove the measuring circuit components and reconnect the LOAD. This concludes the compensation adjustment.

NOTE: TO INSURE MAXIMUM ACCURACY, AND DEPENDABLE OPERATION, THE PROCEDURES DESCRIBED IN THE PREVIOUS PARAGRAPHS (3-15 THROUGH 3-23) SHOULD BE APPLIED BEFORE EACH PROGRAMMING APPLICATION.

3-24 OUTPUT VOLTAGE CONTROL, USING AN EXTERNAL POTENTIOMETER

3-25 GENERAL. By using one of the internal reference sources of the OPS (+E_r) to provide the input voltage (E_i), the OPS output voltage can be controlled by means of an external potentiometer. As in the previously described application (refer to par. 3-4 to 3-7), the transfer function for this control method can be expressed by :

$$E_o = E_i (R_f/R_i) \quad (Eq. 1), \quad \text{where: } E_o = \text{OPS Output Voltage}$$

$$E_i = \text{External Control Voltage}$$

$$R_f = \text{OPS (Fixed) Feedback Resistor}$$

$$R_i = \text{External Input Resistor}$$

3-26 The ratio of the internal (fixed) feedback and external input resistor (R_f/R_i) represents the (fixed) closed-loop gain of the OPS. If the external input resistor (R_i) is chosen to be 5 k ohm this ratio is dimensioned for each OPS model such that a 0–5 volt input voltage will produce the full output range.

3-27 The input voltage (E_i) is derived from the OPS reference source (+E_r) via a resistive divider, consisting of the EXTERNAL VOLTAGE CONTROL potentiometer and the E_o CAL. rheostat. Since the noninverting input of the PREAMPLIFIER is used in this control method, only the small amplifier bias current (Nanoampere Range) will flow through the potentiometer arm. Control linearity and absolute accuracy are, therefore, limited only by the linearity of the potentiometer and calibration of the final circuit.

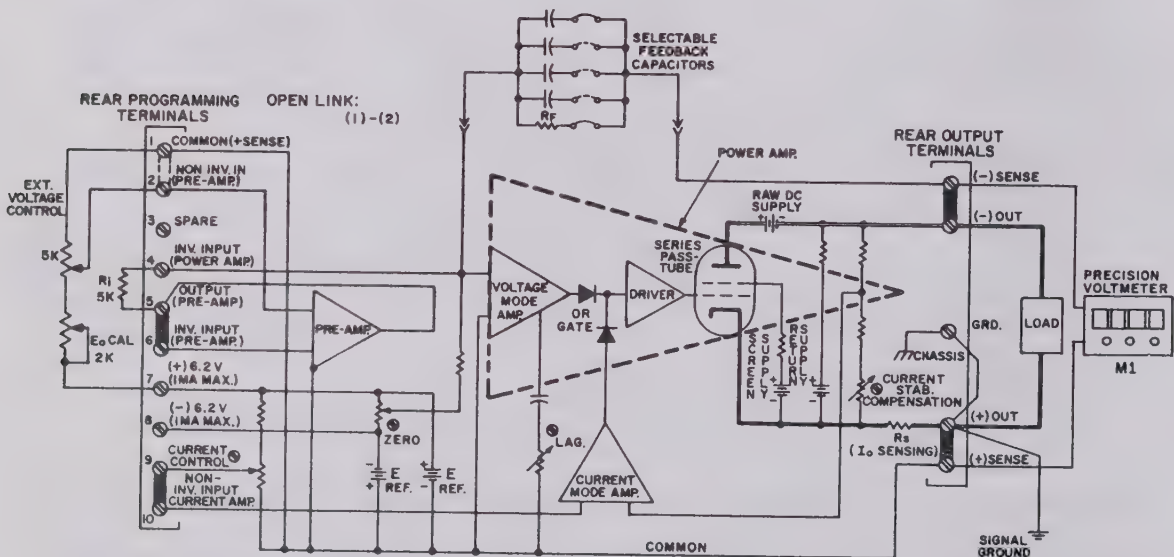


FIG. 3-7 CONNECTIONS FOR OPS OUTPUT VOLTAGE CONTROL WITH A POTENTIOMETER.

3-28 POTENTIOMETER CONTROL, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) Connect the potentiometer (EXTERNAL VOLTAGE CONTROL), the calibrating rheostat (E_o CAL.), the LOAD and the OUTPUT VOLTMETER (M1) to the OPS as shown in FIG. 3-7. FOR INTERCONNECTION DETAILS AND PRECAUTIONS, TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.
- 2) Turn the EXTERNAL VOLTAGE CONTROL to the position yielding minimum output. Turn OPS "on."
- 3) Vary the EXTERNAL VOLTAGE CONTROL through its complete range. The OPS output, as read out on M1, should vary from approximately zero to its maximum rated output voltage. Return EXTERNAL VOLTAGE CONTROL to the "initial" position.

3-29 CALIBRATION (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) Check the OUTPUT VOLTMETER (M1) for zero reading and correct if necessary by adjusting the OPS ZERO control.
- 2) Set EXTERNAL VOLTAGE CONTROL to its maximum position. Observe OUTPUT VOLTMETER (M1). Calibrate the output voltage to the exact maximum rated voltage of the OPS by adjusting the external rheostat (E_O CAL.) to this value.
- 3) Set EXTERNAL VOLTAGE CONTROL to zero again, recheck the previously calibrated zero point on M1 and correct with the OPS ZERO control if necessary.

NOTE: FOR DYNAMIC and OUTPUT CURRENT ADJUSTMENTS, refer to paragraphs 3-15 through 3-23.

3-30 OUTPUT VOLTAGE CONTROL BY A LINEAR RESISTANCE CHANGE

3-31 GENERAL. The OPS output voltage can be controlled by a resistance decade or other linearly varying resistors. Using again a 5 k ohm input resistor for the POWER AMPLIFIER, a 0–5 volt input control voltage (produced by the PREAMPLIFIER) will, with the built-in fixed feedback resistor, produce the full output voltage range.

3-32 The 0–5 volt control voltage input to the POWER AMPLIFIER will now be produced by the UNCOMMITTED PREAMPLIFIER. Connecting the internal built-in d-c reference source with an external variable feedback resistor to the inverting input of the PREAMPLIFIER, the output of the PREAMPLIFIER now constitutes the required control voltage for the POWER AMPLIFIER (refer to FIG. 3-8).

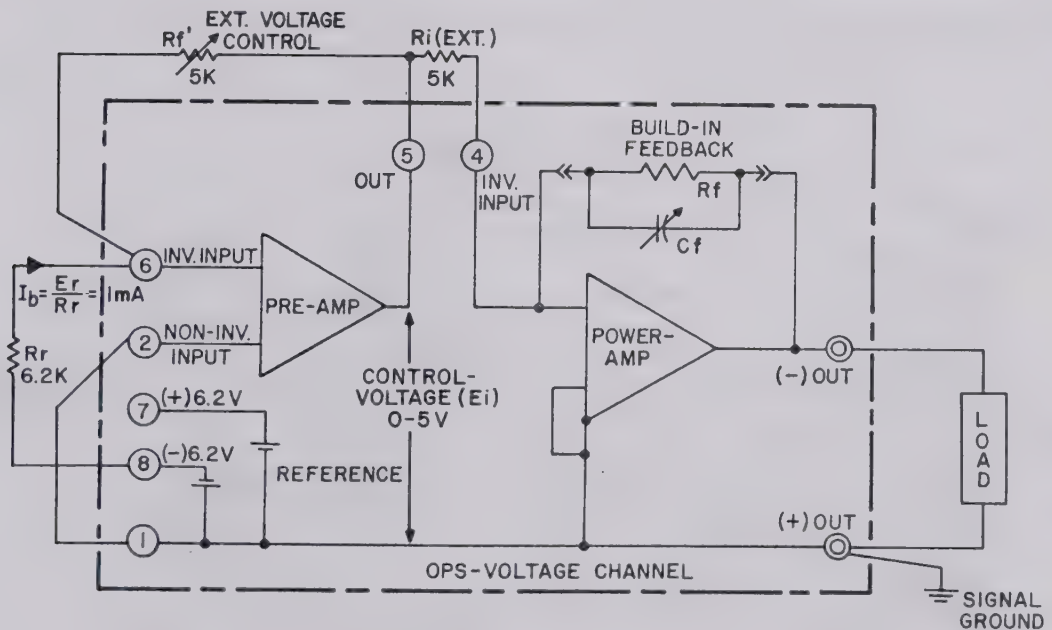


FIG. 3-8 LINEAR OUTPUT CONTROL BY RESISTANCE, OPS VOLTAGE CONTROL CHANNEL.

3-33 As seen from FIG. 3-8, the equation for the output of the PREAMPLIFIER can be expressed by:

$$E_i = \frac{E_r}{R_r} (R_f'), \text{ or}$$

$$0-5 \text{ Volts} = \frac{6.2\text{V}}{6.2 \text{ k}\Omega} (0-5 \text{ k ohms}).$$

By means of the given equation, other values for the external components (R_r , R_f' , R_i) may be chosen if the suggested values are not available.

3-34 LINEAR RESISTANCE CONTROL, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) Connect the selected feedback resistor (R_f = EXTERNAL VOLTAGE CONTROL), the reference resistor (R_r = 6.2 k ohm, Note: Make part of R_r adjustable for E_o CAL. control), the LOAD and the OUTPUT VOLTMETER (M1) to the OPS as shown in FIG. 3-9. NOTE: FOR INTERCONNECTION DETAILS AND PRECAUTIONS, TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.
- 2) Turn the EXTERNAL VOLTAGE CONTROL to its minimum resistance position. Turn OPS "on."
- 3) Vary the EXTERNAL VOLTAGE CONTROL from its minimum to its maximum resistance position. The OPS output, as read out on M1, should vary from approximately zero to its maximum rated output voltage. Return EXTERNAL VOLTAGE CONTROL to its minimum resistance position.

3-35 CALIBRATION

- 1) Check the OUTPUT VOLTMETER (M1) for "zero" reading and correct if necessary by adjusting the OPS ZERO control.
- 2) Set EXTERNAL VOLTAGE CONTROL to its maximum resistance position. Observe the OUTPUT VOLTMETER (M1). Calibrate the output voltage to the exact maximum rated OPS output voltage by adjusting the external reference resistor (E_o CAL.) to this value.
- 3) Set EXTERNAL VOLTAGE CONTROL to "zero" again, recheck the previously calibrated zero point on M1 and correct with the OPS ZERO control if necessary.

NOTE: For DYNAMIC and OUTPUT CURRENT ADJUSTMENTS, refer to paragraphs 3-15 through 3-23.

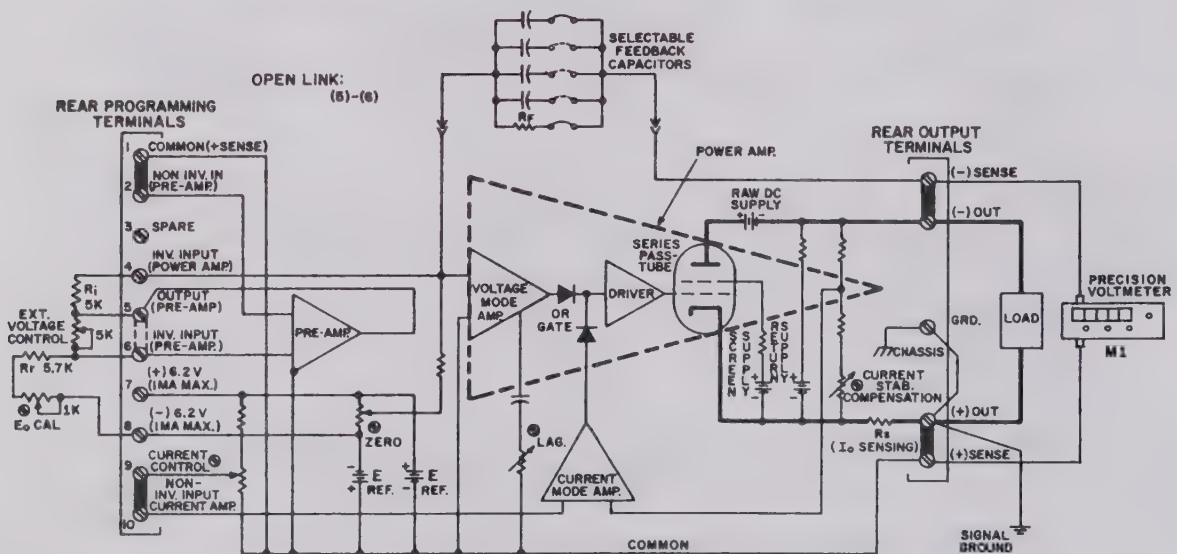


FIG. 3-9 CONNECTIONS FOR OPS OUTPUT VOLTAGE CONTROL BY A LINEAR RESISTANCE.

THE OPS AS A UNIPOLAR AMPLIFIER

3-36 GENERAL. If, instead of the previously used d-c control signal, an a-c signal is applied to the input, the OPS functions as a unipolar amplifier.

The maximum peak-to-peak amplitude of the individual OPS model is equal to its rated d-c output voltage. The average sine wave power into a resistive load is one-quarter its d-c output power. The maximum, full power sine wave frequency is given by:

$$f_{\max} \approx \frac{S. R.}{\pi E_O \max}, \text{ where "S. R."}$$

is the specified OPS slewing rate, and " $E_O \max$ " is the rated maximum output voltage. The "-3 dB frequency" for the OPS, as a unipolar amplifier, is equal to:

$$f_{(-3 \text{ dB})} \approx \frac{0.16}{\tau}, \text{ where } \tau \text{ is the OPS time constant: } R_f C_f \text{ (} R_f = \text{Feedback Resistor, } C_f = \text{Feedback Capacitor).}$$

3-37 Since the output of the OPS can vary only in one direction (negative with reference to the COMMON terminal), for **bipolar** input waveforms, the OPS output must first be d-c biased to accommodate the resulting output waveform (refer to FIG. 3-10.)

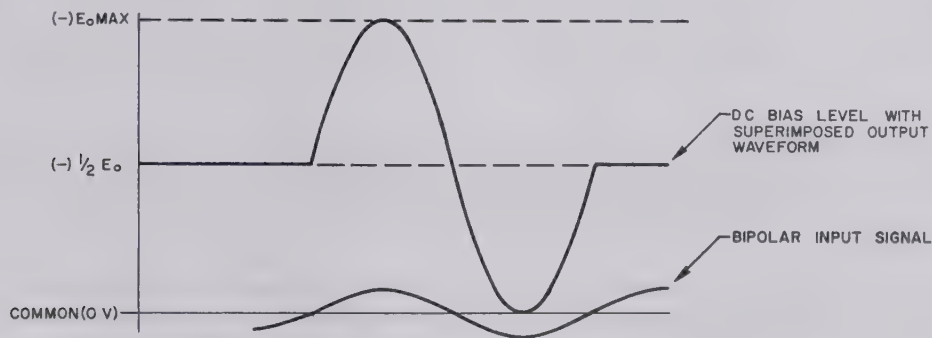


FIG. 3-10 OPS INPUT/OUTPUT WAVEFORMS WITH D-C BIAS.

3-38 The d-c output bias level can be produced by summing a d-c control current (I_b), derived from the internal reference source (E_r), with the a-c input signal (E_i'), at the inverting input of the uncommitted PREAMPLIFIER (see FIG. 3-11).

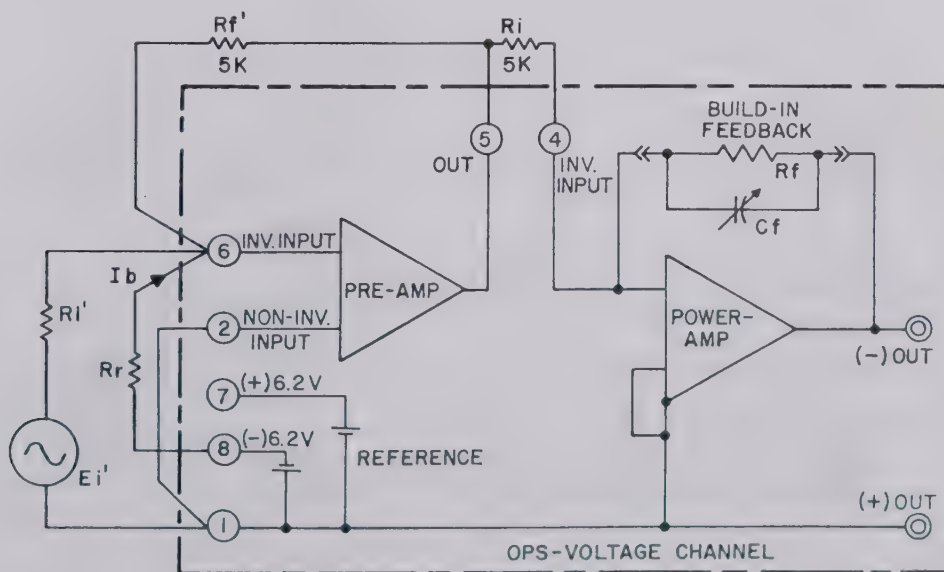


FIG. 3-11 PROGRAMMING WITH A BIPOLAR INPUT SOURCE, OPS VOLTAGE CONTROL CHANNEL.

3-39 Component selection can be best shown by considering a practical application example:

- 1) An OPS 3500 is to be programmed with a sinusoid through its full output range, using a bipolar signal generator.
- 2) As seen in previous paragraphs, to control the OPS output voltage over its rated range, we require a control voltage (E_i) of zero to 5 volts at the input of the POWER AMPLIFIER, and an external input resistor (R_i) of 5 k ohms (refer to pars. 3-4 to 3-7).
- 3) Since the input signal is bipolar, an output bias level of (-) 1750 volts d-c must be set at the OPS output. This requires a bias input of $E_i = (+) 2.5$ volts d-c. To modulate the output from the (-) 1750 volts d-c center, between zero and (-) 3500 volts d-c, requires a modulation of the input voltage (E_i) from the (+) 2.5 volts d-c center, between zero and (+) 5 volts.
- 4) The two equations, expressing the required input conditions are:

$$+E_i (2.5V \text{ d-c}) = -E_r \frac{R_f}{R_i} \text{ and}$$

$$\pm E_i (\pm 2.5V \text{ a-c}) = \pm E_i' \frac{R_f}{R_i}, \text{ where: } \begin{array}{ll} E_i \text{ d-c} & = \text{Required Bias Input Voltage} \\ E_i \text{ a-c} & = \text{Required Signal Input Voltage} \\ E_i' & = \text{Generator Input Voltage} \\ E_r & = \text{Internal Reference Voltage} \\ R_f & = \text{External Feedback Resistor} \\ R_i & = \text{External Input Resistor} \\ R_r & = \text{External Reference Resistor} \\ R_f/R_i & = \text{Closed-Loop Gain, a-c PRE-AMP} \\ R_f/R_r & = \text{Closed-Loop Gain, d-c AMP} \end{array}$$

- 5) The values of the external feedback and input resistors (R_f , R_i) and thereby the (a-c) closed-loop gain, are determined by the output capabilities of the signal generator. If a generator voltage (E_i') of 0 to ± 2.5 volts is available, the ratio R_f/R_i can be made unity. The value of R_f and R_i is chosen according to the generator impedance, if for example, the generator output is specified as "5V p-p at 1 mA," $R_i = R_f$ could be two 5 k ohm resistors.
- 6) Since R_f has been selected according to the capabilities of the input source, the reference resistor (R_r) is calculated by using the equation for the d-c bias conditions. All quantities, except R_r are known, so that:

$$R_r = \frac{6.2V (5 \text{ k ohm})}{2.5V} = 12.4 \text{ k ohm.}$$

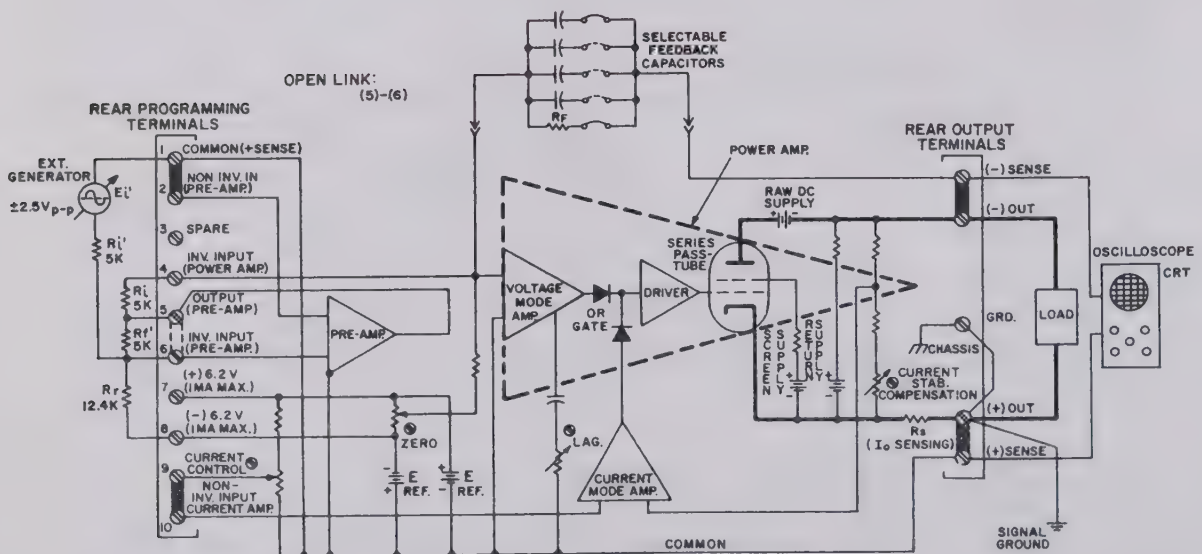


FIG. 3-12 CONNECTIONS FOR AMPLIFYING A BIPOLAR INPUT SIGNAL.

3-40 UNIPOLAR OPERATION, PROCEDURE (refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) Connect the generator (E_i), the LOAD and an oscilloscope (CRT) to the OPS as shown in FIG. 3-12. FOR INTERCONNECTION DETAILS AND SAFETY PRECAUTIONS TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.
- 2) Set generator (E_i) amplitude to "zero." Turn the OPS and the generator "on."
- 3) Adjust generator amplitude from zero to 5 volts peak-to-peak. The oscilloscope at the OPS output should display a sine wave, varying from zero to the maximum rated OPS output voltage. Return generator amplitude to "zero." TURN OPS POWER SWITCH OFF.

3-41 CALIBRATION

- 1) Establish the "zero" level on the oscilloscope by briefly connecting the scope lead to the "common" lead. Reconnect oscilloscope to the OPS output.
- 2) TURN OPS "on." Adjust the generator amplitude to 5 volts p-p and observe the output sine wave:
 - a) Correct "zero" level with the OPS ZERO control.
 - b) Correct maximum output amplitude with the generator amplitude control.

NOTE: 1) If "clipping" of the output waveform is evident, the d-c bias is probably not exactly at one-half E_O max. Correct by making R_f partially adjustable.

2) Refer to pars., 3-15 through 3-23 for the procedures for DYNAMIC and OUTPUT CURRENT adjustments.

3-42 For input sources other than the bipolar sine wave generator used in the previous application, the process of component selection and the equations for the control voltage (E_i) are similar. The following criteria should be kept in mind for *all* applications where the OPS is used as a unipolar amplifier:

The programming connections from external input sources to the OPS should be "tailored" according to the input source polarity and capability:

- a) **BIPOLAR** input sources require a d-c bias producing *one-half* the required OPS output level. For input sources able to supply at least 1 milliamperes of programming current, the POWER AMPLIFIER input can be driven directly. For high impedance input sources, the inverting input of the PREAMPLIFIER can be used. The d-c bias is produced by summing a d-c control current, derived from the internal reference source, with the a-c signal at the inverting input of the PREAMPLIFIER (see PAR. 3-38).
- b) **POSITIVE**-going input sources can drive the inverting input of the POWER AMPLIFIER directly. A drive current of 1 milliamperes, via a 5 k ohm input resistor must be supplied by a 0–5 volt input source to program the OPS from zero to its maximum rated output voltage with the built-in feedback resistor. Alternately, the noninverting input of the PREAMPLIFIER can be driven by high impedance input sources. The PREAMPLIFIER is configured as a "voltage follower" and its output is connected (via a 5 k ohm input resistor) to the inverting input of the POWER AMPLIFIER. A 0–5 volt input source will thus program the OPS from zero to its maximum rated output voltage.
- c) **NEGATIVE**-going input sources should be connected to the inverting input of the PREAMPLIFIER. The gain of the PREAMPLIFIER is adjusted by selecting appropriate external resistors and calculated such that the output of the PREAMPLIFIER produces a 0–5 volt control signal at the inverting input of the POWER AMPLIFIER, to program the OPS from zero to its maximum rated output voltage.

NOTE: For DYNAMIC and OUTPUT CURRENT ADJUSTMENTS refer to paragraphs 3-15 through 3-23.

THE OPS AS A CURRENT CONTROLLER

3-43 OUTPUT CURRENT CONTROL BY MEANS OF AN EXTERNAL CONTROL VOLTAGE OR BY A POTENTIOMETER

3-44 GENERAL. By disconnecting the current control amplifier from its internal control (open link 9–10 at the REAR PROGRAMMING TERMINALS) and substituting an external d-c control voltage (≈ 0 –1 volt), the output current of the OPS can be remotely controlled over its specified range.

3-45 The external d-c control voltage may be produced, for example, by a digital programmer, such as the Kepco SN–2, thus permitting digital control of the OPS output current from a computer. Another method of remote control of the OPS output current consists of duplicating the internal control method by means of an external potentiometer.

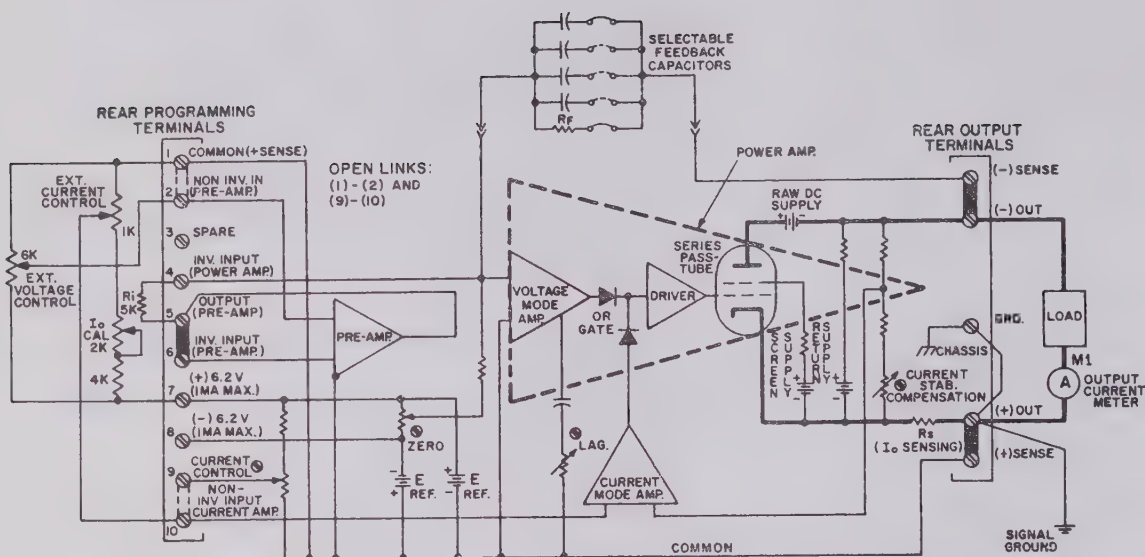


FIG. 3-13 CONNECTIONS FOR OUTPUT CURRENT CONTROL, USING AN EXTERNAL POTENTIOMETER.

3-46 CURRENT CONTROL BY EXTERNAL POTENTIOMETER, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) This control method duplicates the internal OPS current control circuit. The internal reference source (+6.2V) is used with a series resistor and a calibrating rheostat (I_O CAL.) to produce the control voltage (1 volt) across the potentiometer (EXTERNAL CURRENT CONTROL). The required compliance (output) voltage can be adjusted by the EXTERNAL VOLTAGE CONTROL potentiometer.
- 2) Refer to FIG. 3-13, Connect all external components as shown. Turn OPS "on." Adjust the EXTERNAL VOLTAGE CONTROL to the required load compliance voltage. Adjust the EXTERNAL CURRENT CONTROL to the position yielding the minimum output current.
- 3) Slowly, turn the EXTERNAL CURRENT CONTROL through its range. The OPS output current, as read out on M1, should vary smoothly from approximately zero to its maximum rated output current. Return EXTERNAL CURRENT CONTROL to the position yielding the minimum output current.

NOTE: The output current value can also be measured indirectly by means of the precision voltmeter across a current measuring resistor (R_M). R_M should be selected such that a convenient range on the precision voltmeter can be used, e.g., for a 10 milliamper output current, use a 100 ohm resistor to produce one volt full scale. If an electronic voltmeter is used, it should be battery-operated to avoid ground loops.

3-47 CALIBRATION

- 1) The output current control range for the OPS is approximately 2%–100% of the specified output current capacity. The lower end of the range will depend on the offsets of the OPS CURRENT AMPLIFIER. No provisions for calibrating this offset (practical values for this offset from zero $\approx 100 \mu A$) have been made. If a precise "zero" point is required, an alternate mode for precision current programming with the voltage mode amplifier should be chosen (refer to par. 3-50).
- 2) Set EXTERNAL CURRENT CONTROL to the position yielding the maximum output current. Observe the OUTPUT CURRENT METER. Calibrate the output current of the maximum rated value by adjusting the rheostat (I_O CAL.) to this value.

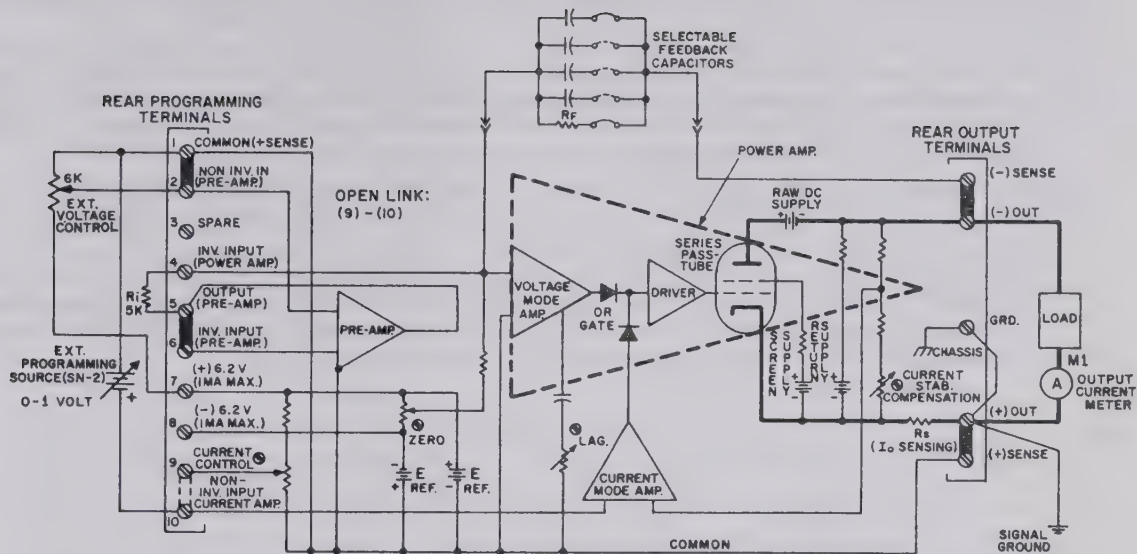


FIG. 3-14 CONNECTIONS FOR OUTPUT CURRENT CONTROL, USING AN EXTERNAL CONTROL VOLTAGE.

3-48 CURRENT CONTROL BY AN EXTERNAL CONTROL VOLTAGE, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- 1) This control method is often used in combination with a Kepco SN Digital Programmer, although any stabilized, positive-going d-c source variable from zero to approximately 1 volt can be used. The Kepco Model SN-2, for example, can deliver an input control signal from zero to 1 volt by setting its "ATTENUATOR SELECTOR" to the "IV" position. It has a built-in zeroing control and linearity of $\pm 0.2\%$. The SN Programmer can be addressed manually (with a Kepco MPG-2 keyboard) or by machine (parallel input, 10 lines).
- 2) Refer to FIG. 3-14. The Kepco SN-2 is used as the EXTERNAL PROGRAMMING SOURCE, producing the control voltage between the "common" and the current amp input. The required compliance (output) voltage can be adjusted by the EXTERNAL VOLTAGE CONTROL potentiometer.
- 3) Refer to FIG. 3-14. Connect all external components as shown. Turn the Kepco SN-2 "on" and set to zero. Turn OPS "on." Set EXTERNAL VOLTAGE CONTROL to the required load compliance voltage.
- 4) Increase the programming voltage from the SN from "zero" to 1 volt. The OPS output current as read out on M1 should follow proportionately from approximately zero to the maximum rated value. Return programming voltage from the SN to "zero."

3-49 CALIBRATION

- 1) Check the OUTPUT CURRENT METER (M1) for "zero" reading. Adjust to zero by means of the SN ZERO control.
- 2) Set SN programmer for 1 volt output. Check M1 and calibrate for the maximum rated OPS output current by means of the SN FULL SCALE control (optional control). (SN models with suffix "R" only.)
- 3) Reset SN Programmer to "zero" and recheck the previously calibrated "zero" point on M1. Correct with the SN ZERO control if necessary.

3-50 OUTPUT CURRENT CONTROL (MICROAMPERE RANGE) USING THE VOLTAGE MODE AMPLIFIER

3-51 GENERAL. The internal shunt loads and the restrictions imposed by a single internal sensing resistor in the OPS current control circuit preclude the use of the CURRENT MODE AMPLIFIER for the control of output currents in the microampere range. For applications requiring stabilized output currents in this range, an operating mode using the VOLTAGE MODE AMPLIFIER can be chosen. Two basic control methods, suitable for output currents in the microampere range are described in the following paragraphs.

3-52 THE CONTROL OF SMALL OUTPUT CURRENTS, WITH THE LOAD IN THE FEEDBACK LOOP. In the first control method (see FIG. 3-15) the load is placed across the feedback terminals of the power amplifier section and must be completely "floating" (off ground).

This current control method is useful for applications where the load (compliance) voltage must be closely monitored. A precision voltmeter may be placed across the unused output terminals since these terminals repeat the voltage across the load at a low impedance. The built-in preamplifier of the OPS is used to repeat the control voltage, derived from the internal reference potential (see FIG. 3-15).

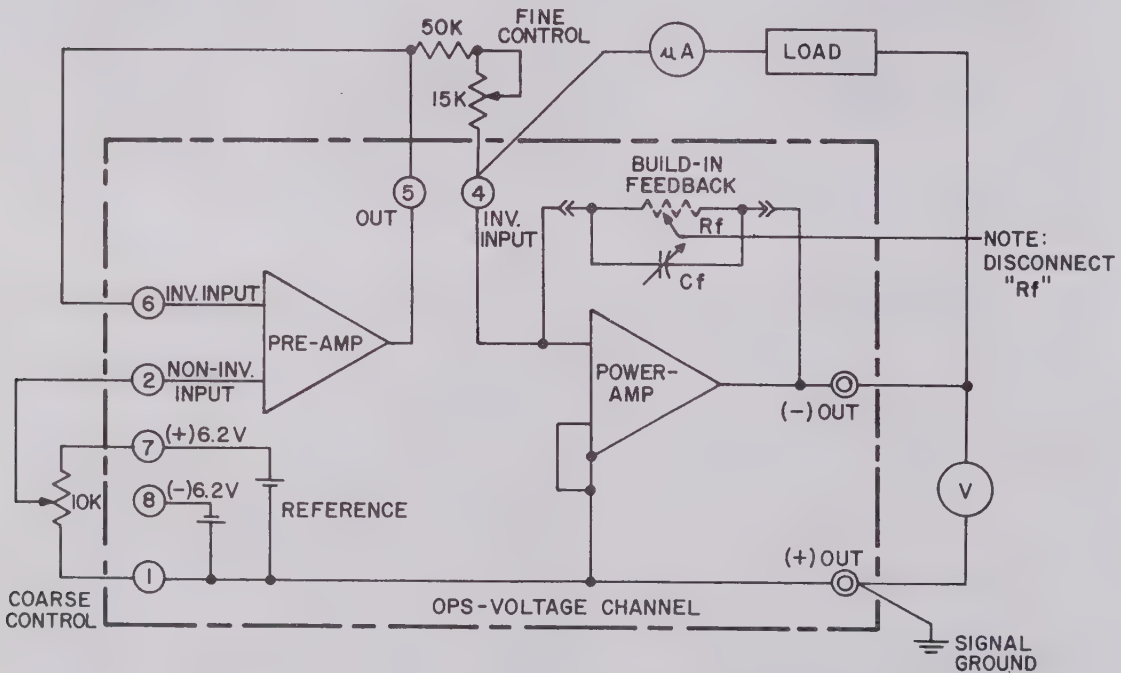


FIG. 3-15 EQUIVALENT DIAGRAM, OPS VOLTAGE CONTROL CHANNEL CONNECTED FOR THE CONTROL OF OUTPUT CURRENTS IN THE RANGE OF 0-100 μ A.

3-53 OUTPUT EQUATION. The output equation for this control method is derived from the equivalent diagram (FIG. 3-15) and is given by:

At $e = 0$ and $I_{i0} = 0$ (Amplifier input = 0):

$$I_o = \frac{E_{CC}}{R_C}$$

NOTE: The maximum output current (I_o) in this circuit is limited by the capability of the PRE-AMP (5 mA max.).

where: E_{CC} is the control voltage either applied externally, or derived from the internal reference voltage (E_r) and applied via the preamplifier. (See FIG. 3-15.)

R_C = Current Calibrating Resistor, consisting of a fixed and an adjustable component.

I_o = Output Current.

3-54 As seen from the output equation, the output current (I_o) varies linearly with the control voltage (E_{CC}) and inversely with variations in the value of the calibrating resistor (R_C). Either the control voltage, or the calibrating resistor can, therefore, be used to control the magnitude of the output current.

- 3-55 **COMPONENT SELECTION.** To summarize the material presented in the previous paragraphs (3-50 to 3-54) and to illustrate component selection, a sample application is described below and shown in FIG. 3-16.
- 3-56 An OPS is used to deliver stabilized output current from zero to 100 microamperes into a fixed load. The control voltage (E_{CC}) will be derived from a potentiometer across the internal reference source and applied via the preamplifier, operated as a voltage repeater. From the output equation, we have: $E_{CC}/I_O = R_C$, or $6.2V/100\ \mu A = 62\ k\ \text{ohm}$ for the maximum value of the calibrating resistor. With the potentiometer controlling E_{CC} serving as a "coarse control," a part of R_C may be made adjustable to serve as a calibrating control for the output current.
- 3-57 Connect all components as shown in FIG. 3-16. The leads going to the preamplifier and power amplifier inputs should be shielded for minimum noise pick-up. The shield must be connected (single-ended) to the signal ground point.

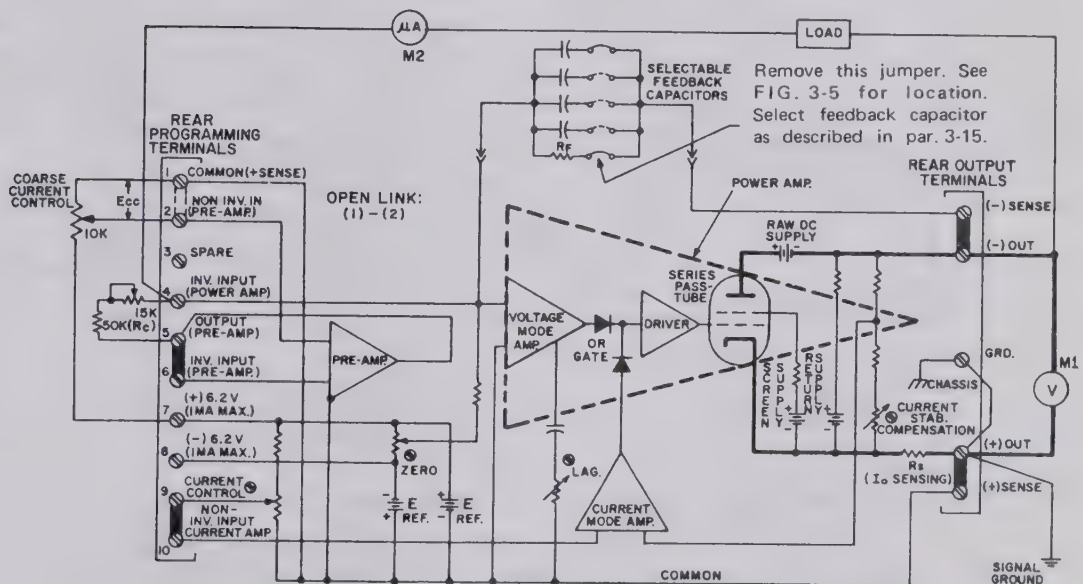


FIG. 3-16 EXTERNAL CONTROL OF THE OUTPUT CURRENT, USING THE VOLTAGE MODE AMPLIFIER. (LOAD COMMON TO THE (-) OUTPUT TERMINAL).

- 3-58 **CALIBRATION** (See Section II, FIG. 2-1 or FIG. 2-2 for the location of all calibrating controls)
- Turn OPS "on" and allow circuit to reach thermal equilibrium.
 - Set the COARSE CURRENT CONTROL to the position of maximum output current.
 - Calibrate for exactly $100\ \mu A$ by means of the CALIBRATING CONTROL (R_C).
 - Set the COARSE CURRENT CONTROL to the position of minimum output current. Calibrate for zero by means of the (internal) ZERO CONTROL.
 - Recheck maximum output current calibration by repeating (b) and (c).
- 3-59 **OUTPUT MEASUREMENTS.** Output effects may be measured with the microammeter in series with the load (See FIG. 3-16.) With the current monitor (M2) in the position shown, a high voltage isolated measuring device is not needed and the output current measurements can be performed directly.
- 3-60 **UNPROGRAMMED OUTPUT DEVIATIONS (RIPPLE AND NOISE).** The output ripple may be observed across the voltage monitor (M1). The observed ripple voltage must be converted into current units by dividing the observed rms or p-p ripple voltage by the value of the load resistance.

3-61 EXTERNAL CURRENT SENSING AND VOLTAGE CONTROL

3-62 In this control method the load is operated close to the (+) output terminal (common), while the control source is located in the feedback loop. The control voltage must be a stabilized, positive-going d-c source, variable from zero to 10 volts (at about 100 μ A) and it should have its own calibrating controls. The Kepco Model SN-2 Programmer, for example, has been used very successfully in this application. The SN can deliver a 0-10 volt input signal (manually selectable two decades) and can be addressed manually (with a Kepco MPG-2 keyboard) or by machine (parallel input, 10 lines).

3-63 The transfer function for output control by voltage is derived from FIG. 3-17 below and can be expressed by:

$$I_O = E_{CC}/R_S \quad (\text{Eq. 3}), \quad \text{where: } I_O = \text{Desired Maximum Output Current}$$

$$E_{CC} = \text{External Control Voltage}$$

$$R_S = \text{Current Sensing Resistor (See Note)}$$

NOTE: This equation (Eq. 3) is derived from the equivalent diagram (FIG. 3-17), and is valid for the "zeroed" OPS. The range of the internal OPS ZERO control permits sensing resistor values up to approximately 50 k ohm.

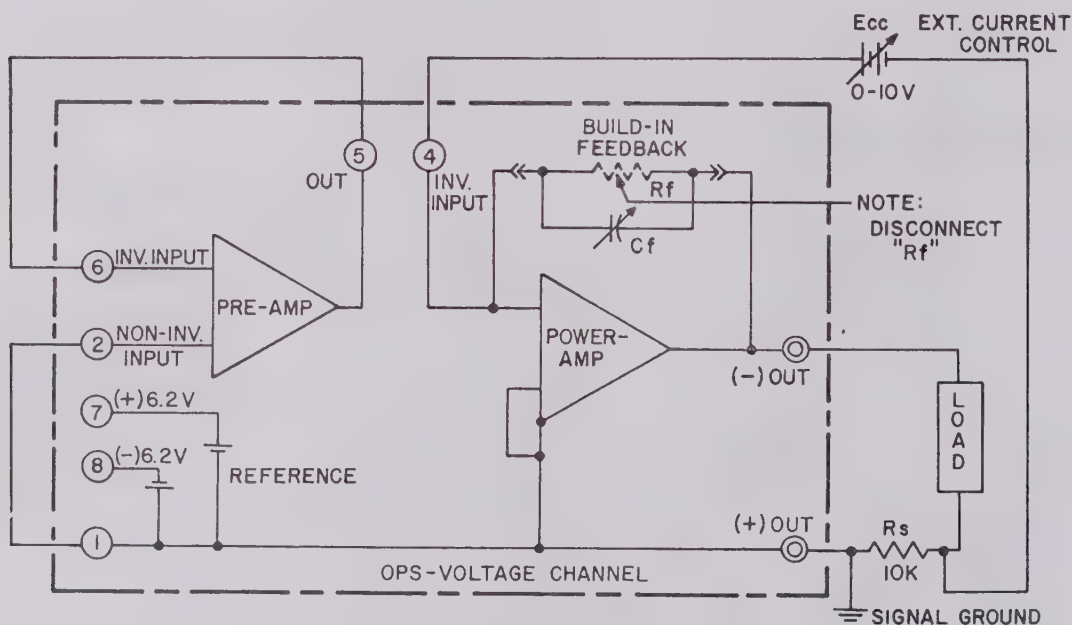


FIG. 3-17 EQUIVALENT DIAGRAM, OPS WITH EXTERNAL SENSING AND OUTPUT CURRENT CONTROL BY A CONTROL VOLTAGE.

3-64 The circuit shown in FIG. 3-17 is suitable for output current from the rated maximum output current down to 1 microampere. The necessary value for the sensing resistor (R_S) is given in FIG. 3-17 for a control voltage (E_{CC}) of 0-10 volts and an output current range of 0-1 milliamperere. For other control voltages and/or output current ranges, R_S can be calculated using the output equation (Eq. 3).

3-65 The external control voltage (E_{CC}) may simply consist of a potentiometer across a mercury cell or it may be a controlled voltage source, such as the Kepco Model SN-2 (refer to par. 3-62). The voltage source (E_{CC}) must be stable, but its current capacity can be quite small (microampere range).

3-66 EXAMPLE I. An OPS model is used to deliver stabilized output current from 0 to 1 milliampere. The actual connecting pattern for the circuit with external sensing and voltage control is illustrated in FIG. 3-18. Connect all components as shown in FIG. 3-18, locating the sensing resistor as close as possible to the power supply. The leads connecting the control voltage (E_{CC}) must be shielded, with the shield (single-ended) connected to the common signal ground point. This ground point must be selected carefully to avoid possible ground-loop effects.

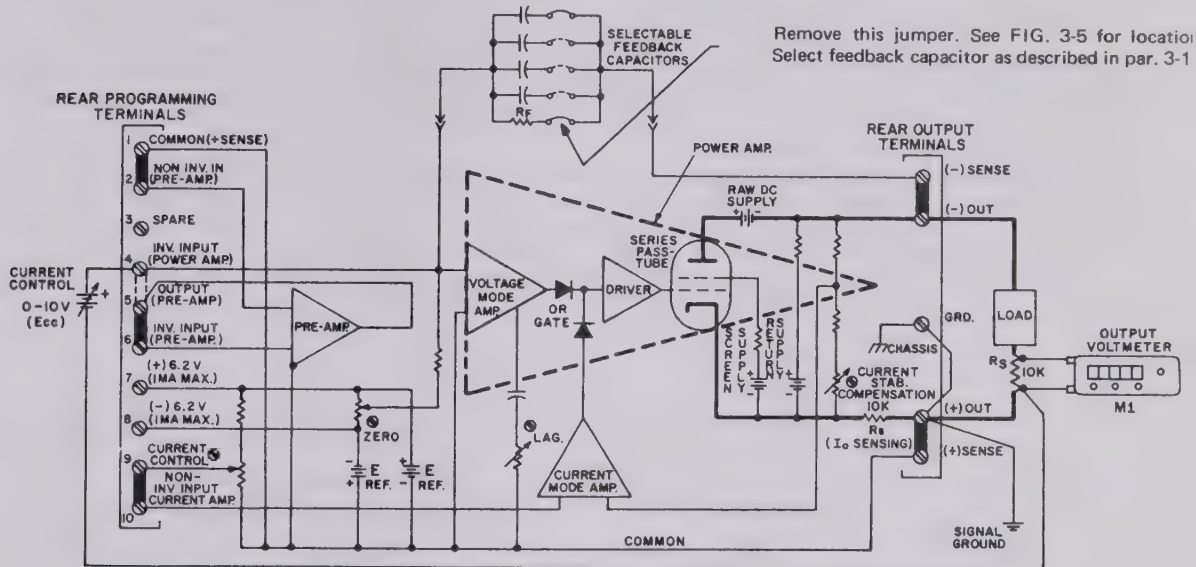


FIG. 3-18 EXTERNAL SENSING AND VOLTAGE CONTROL OF THE OUTPUT CURRENT (I_O SETTING RANGE = 0–1 mA).

3-67 CALIBRATING THE OUTPUT (See Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

- Turn OPS "on" and allow circuit to reach thermal equilibrium.
- The maximum output current (I_O max) must be calibrated as the control voltage (E_{CC}).
- Set E_{CC} to zero and calibrate for zero output current by means of the OPS ZERO control.
- Recheck maximum output current calibration and correct by resetting E_{CC} if necessary.

3-68 OUTPUT MEASUREMENTS. Stabilization and ripple measurements may be performed by using the methods described in previous paragraphs (refer to pars. 3-59 to 3-60).

SECTION IV – THEORY OF OPERATION

4-1 GENERAL

- 4-2 A **Standard Power Supply** is not well suited for tasks requiring a fast output response. It is generally optimized as a **Voltage Source** and its bandwidth is deliberately restricted, mainly by means of a large output capacitor. The standard power supply is designed to approach the characteristics of an ideal voltage source: low output ripple, low source resistance and a large storage capability.
- 4-3 By contrast, an **Operational Power Supply** exhibits the characteristics deliberately suppressed in a standard power supply: wide bandwidth and fast output response. The wide-band characteristic is achieved by removing the large capacitor at the output and shaping the open-loop response by means of lag networks. The trade-offs which must be accepted are: higher output ripple and output impedance and restrictions on reactive loading.
- 4-4 An **Operational Power Supply** can, however, perform tasks which would be impossible for a standard supply: as a **D-C Power Source**, it can be programmed to provide high speed voltage or current level changes. As a **Unipolar Power Amplifier**, it can amplify unipolar or bipolar waveforms to power levels limited only by its own output ratings. As an **Operational Amplifier** it can serve as a summer, scaler or integrator, and can perform any other operational task. In addition, the Operational Power Supply, with its wide bandwidth and its fast response to load voltage changes, is ideally suited to function as a **Stabilized Current Source**.

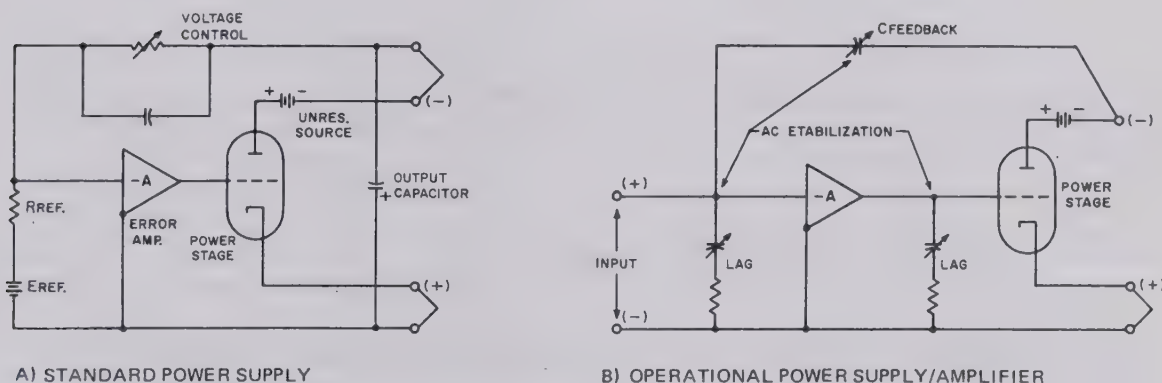


FIG. 4-1 COMPARISON: STANDARD POWER SUPPLY WITH AN OPERATIONAL POWER SUPPLY.

4-5 OPERATIONAL POWER SUPPLY SPECIFICATIONS

- 4-6 GENERAL. The performance of Operational Power Supplies is described in terms of the following parameters:
- 1) D-C OFFSET VARIATIONS.
 - 2) OPEN-LOOP GAIN (Specified at d-c).
 - 3) MAXIMUM SLEWING RATE.
 - 4) MAXIMUM SINE WAVE FREQUENCY (FULL POWER).
 - 5) PROGRAMMING TIME CONSTANT.
- 4-7 Since there are no established standards to describe the behavior of Operational Power Supplies, the terms used by Kepco, Inc., are defined in the following paragraphs. The discussion includes the test circuitry used to establish the specifications, as well as notes on their application.
- 4-8 D-C OFFSET VARIATIONS. Most Kepco power supplies, "standard" or "operational," consist of a comparison amplifier, a reference source and a power amplifier section. (Refer to FIG. 4-1.) The effects of various external influences, such as time, temperature, load or a-c source variations upon the d-c output of *any* power supply are due to small variations at the input of the comparison amplifier. These small errors or "offset variations" are transferred to the output, amplified by a factor which depends on the gain (ratio of reference voltage to output voltage) and the value of the feedback resistor (voltage control resistor) at any given output level. Since a "standard" power supply has only a limited range of gain and feedback resistance,

the total "worst case" error can be specified *directly* as an *output effect* in response to the various *Influence Quantities*. In an operational power supply, however, the gain and the feedback resistor are selected by the user and may, therefore, vary over a much wider range. For this reason, the *offset variations* are specified for the power supply amplifier input. Once the user has selected the feedback components and the required gain for the application at hand, the output effects can be calculated by means of the *error equation*.

4-9 As seen from FIG. 4-1, an operational power supply can be represented as an amplifier, driving a power stage in series with the raw d-c source. It can, therefore, be analyzed using operational amplifier terminology. The circuit shown in FIG. 4-2 is further simplified by including the power stage and the raw d-c source into the amplifier triangle. Adding an input source (E_i) with a series resistor (R_i) and a feedback resistor (R_f), a model of an "ideal" operational amplifier (inverting configuration) results, for which the following assumptions are made:

- 1) The offset current (I_{iO}) at the input terminal (Null Junction) *approaches* zero.
- 2) The open-loop gain (A) *approaches* infinity ($A \rightarrow \infty$).
- 3) The input voltage (E_{iO}) *approaches* zero, when the feedback loop is closed.

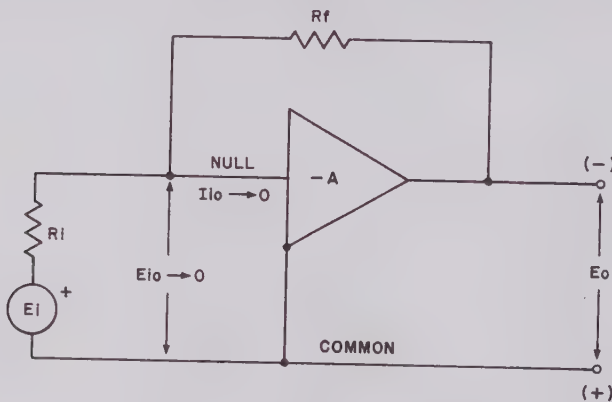


FIG. 4-2 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION).

4-10 Refer to FIG. 4-2. If the input error voltage and current (E_{iO} , I_{iO}) are assumed to be zero, and the gain infinite, we can write:

$$\frac{E_i}{R_i} = \frac{E_o}{R_f} \quad (\text{Eq. 1}),$$

or in the more familiar form,

$$E_o = -E_i \frac{R_f}{R_i} \quad (\text{Eq. 2}),$$

where, the ratio R_f/R_i represents the closed-loop gain. Equation (2) thus becomes the transfer function for the operational amplifier in an inverting configuration. Although the expression (Eq. 2) was derived for the "ideal" case, it may be readily applied to the practical operational power supply circuit. The transfer function (Eq. 2) is, for example, extensively used to calculate the values for the input and feedback resistors, since the associated errors are negligible compared to standard component tolerances. These errors neglected in the "ideal" model must, however, be considered in evaluating the d-c performance at the output of an active operational power supply.

- 4-11 **AMPLIFIER OFFSETS.** In developing the ideal amplifier model, we tacitly assumed the null junction voltage and current to be zero causing the "ideal" equation (2) to be valid. In reality, however, nonidealities do exist at the null junction or input terminal of the amplifier. These errors are of the form of an offset voltage (E_{iO}) and an offset current (I_{iO}). The modified version of the amplifier model can be shown with these error sources as in FIG. 4-3.

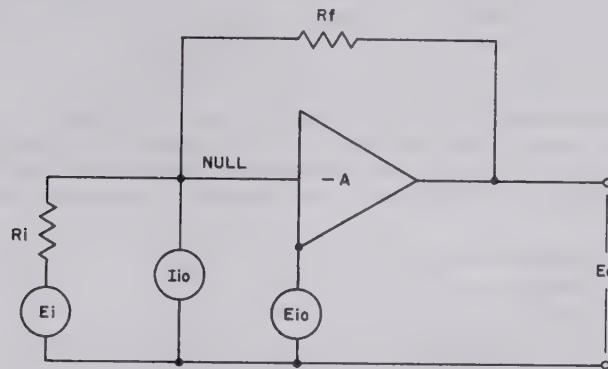


FIG. 4-3 OPS VOLTAGE MODE AMPLIFIER WITH INPUT OFFSET SOURCES.

- 4-12 Although the INITIAL values of both offsets (E_{iO} , I_{iO}) may be cancelled by compensating sources of opposite polarity,⁽¹⁾ the VARIATIONS of the offsets (ΔE_{iO} , ΔI_{iO}) and the variation of the internal reference voltage (ΔE_i) with a-c input source, d-c load, temperature, and time changes *do* exist at the amplifier input and are specified as shown in the table (Table 4-1).

INFLUENCE QUANTITY	OFFSET VARIATIONS		REFERENCE (6.2V $\pm$ 5% NOMINAL) VARIATIONS
	ΔE_{iO}	ΔI_{iO}	
A-C INPUT SOURCE: (105 to 125V or 210 to 250V)	$<10 \mu\text{V}$	$<1 \text{ nA}$	0.0005%
LOAD: No load to full load	$<10 \mu\text{V}$	$<1 \text{ nA}$	NOT APPLICABLE
TIME: 8 hrs. (Drift)	$<20 \mu\text{V}$	$<1 \text{ nA}$	0.005%
TEMPERATURE: Per $^{\circ}\text{C}$	$<20 \mu\text{V}$	$<0.5 \text{ nA}$	0.005%

TABLE 4-2 TYPICAL OFFSET SPECIFICATIONS FOR OPERATIONAL POWER SUPPLIES

- 4-13 For a "worst case" analysis of the effects these tabulated errors have at the output of the operational power supply, their algebraic sum can be expressed by the "Error Equation" (Eq. 3)

$$\Delta E_O = \pm \Delta E_i (R_f/R_i) \pm \Delta E_{iO} (1 + R_f/R_i) \pm \Delta I_{iO} R_f$$

WORST CASE TOTAL OUTPUT EFFECT	OUTPUT EFFECT DUE TO VARIATIONS IN REFERENCE VOLTAGE	OUTPUT EFFECT DUE TO OFFSET VOLTAGE VARIATIONS	OUTPUT EFFECT DUE TO OFFSET CURRENT VARIATIONS
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NOTE: Changes in R_f and R_i as a function of time and temperature are neglected in the above equation. In practical applications, R_f and R_i should have low, matched temperature coefficients, for optimum d-c stability.

⁽¹⁾OPS Power Supplies have a built-in control, (R22 – ZERO) to zero the output voltage with zero input signal and with the built-in feedback resistor (R_f) connected

4-14 An inspection of the individual terms of the error equation (Eq. 3) re-emphasizes the previously discussed reasons for specifying all error voltages separately at the **input** to the power supply amplifier: The magnitude of the **output effects** caused by the individual errors (ΔE_i , ΔE_{iO} , ΔI_{iO}) depend on the **ratio** of the feedback and input resistor (R_f/R_i = closed-loop gain) and on the **value** of the feedback resistor (R_f). Since the gain and the input/feedback components are selected by the user, the total output effect (ΔE_O) must be calculated for each application by means of the error equation. The separation of the terms in the error equation allows the analysis of the contribution of each error to the total output effect and permits component selection so as to minimize the total effect.

4-15 A practical example should illustrate the use of the derived equations and the offset specifications: A Model OPS 1000 is used as a d-c voltage source in an application requiring 1000 volts into a constant load. The available a-c power source is assumed to be stable, but the temperature in the operating environment changes over a range of 10°C . The effect of this temperature on the output voltage of the OPS is to be predicted. Making use of the preamplifier connection as illustrated in Section III (see FIG. 3-3), the given operating parameters are:

R_f = 1 M ohm (built-in feedback resistor).

R_i = 6.2 k ohm (external input resistor).

G = $R_f/R_i \approx 162$ (closed-loop gain).

E_i $\approx$ 6.2 volts (d-c input voltage to set the OPS output to 1000 volts. Derived by resistor divider from the internal OPS reference and applied to the voltage amplifier null junction via the preamplifier and the 6.2 k ohm series input resistor (see for example FIG. 4-6).

Assuming the variations with temperature of the resistors to be negligible, the selected values (G , R_f , R_i) and the offset specifications (from Table 4-1) are now inserted into the error equation (Eq. 3):

$$\begin{aligned} \Delta E_O &= 310 \mu\text{V} (162) + 20 \mu\text{V} (1 + 162) + 0.5 \text{ nA} (1 \times 10^6 \Omega) \\ &= 50.2 \text{ mV} + 3.3 \text{ mV} + 0.5 \text{ mV} \approx 54 \text{ mV per } ^\circ\text{C}. \end{aligned}$$

OUTPUT EFFECT
DUE TO
REFERENCE
VARIATION

OUTPUT EFFECT
DUE TO
OFFSET VOLTAGE
VARIATION

OUTPUT EFFECT
DUE TO
OFFSET CURRENT
VARIATION

or approximately 0.5-volt output voltage change ($\approx 0.05\%$) over the 10°C temperature range. It should be noted, that the calculated total output effect (ΔE_O) represents a "worst case" prediction, assuming all error terms are positive. In practice, this is not the case. A TYPICAL value for the above example would be considerably smaller, as actual measurements on large numbers of operational power supplies have shown.

4-16 OPEN-LOOP GAIN. In the "ideal" transfer function for the operational power supply (Eq. 2), the open-loop gain (A) was assumed to be infinite. In reality, however, it is finite and in the order of 10^5 to 10^7 (volts per volts). Although operational power supplies are seldom used in an open-loop configuration, the open-loop gain (A) is of interest since it provides a measure of the possible programming accuracy. Finite open-loop gain introduces a "gain error" into the "ideal" transfer function (Eq. 2), which limits the absolute closed-loop accuracy and gain linearity. While the absolute closed-loop **accuracy** can be "calibrated away" by adjusting the feedback resistor, the **gain linearity** cannot be corrected. The specified open-loop gain (A), specified at d-c, is a measure of that linearity. To illustrate the significance of the open-loop gain, consider the modified transfer function for the operational power supply in the inverting configuration:

$$\frac{E_O}{E_i} = \frac{(R_f/R_i)}{1 + \frac{1}{A\beta}}, \quad (\text{Eq. 4}),$$

where the "ideal" closed-loop gain ($E_O/E_i = R_f/R_i$) is modified by the error term $1/A\beta$, where A is the open-loop gain, and β represents the feedback ratio (R_i/R_f) (Approximately).

4-17 Assuming that the resistors (R_f , R_i) do not contribute to the gain error, consider an application where:

Specified Open-Loop Gain (A) d-c = 10^6 volts/volt.

Ideal Closed-Loop Gain (R_f/R_i) = 10^2 .

The gain (linearity) error, due to finite open-loop gain, in this case equals:

$$\frac{1}{A \left(\frac{R_i}{R_f} \right)} = 1/10^4, \text{ or } 0.01\%.$$

4-18 DYNAMIC SPECIFICATIONS

- 4-19 **GENERAL.** The output behavior of the operational power supply can be described by two major parameters: The PROGRAMMING TIME CONSTANT and the MAXIMUM SLEWING RATE. The first describes the output response in the linear region while the other represents the output response to overdriven or forced input signals.

- 4-20 **PROGRAMMING TIME CONSTANT.** *The programming time constant (τ) is the time required for an output voltage step to change from 0 to 63% of its final value.*

The programming time constant expresses the programming speed in the linear region of the operational power supply. It is approximately equal to the product of the values of the feedback resistor and the feedback capacitor: $\tau \approx R_f C_f$ and it is measured as the first time constant on the exponential output response.

- 4-21 The "programming time constant" (τ) can readily be translated into the frequency domain, thus yielding the upper "3 dB frequency"; i.e., the highest sine wave frequency the operational power supply output can reproduce in its linear region. Since the programming time constant (τ) represents the rise time of the output voltage (0–63% E_o), it is inversely proportional to the upper 3 dB frequency (f_2):

$$t_r (0-63\%) = \tau = \frac{1}{\omega_2} = \frac{1}{2\pi f_2} = \frac{0.16}{f_2} \quad \text{If, for example, } \tau = 100 \mu\text{sec.}, f_2 = 1.6 \text{ kHz.}$$

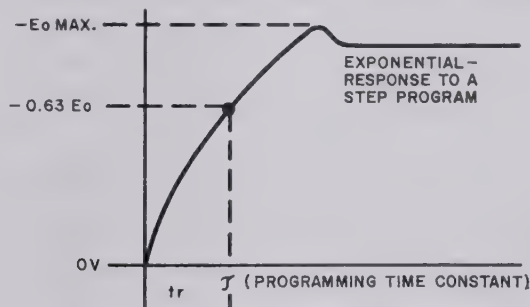


FIG. 4-4 DEFINITION OF THE PROGRAMMING TIME CONSTANT.

- 4-22 **MAXIMUM SLEWING RATE.** *The maximum slewing rate is the fastest time rate of change of which the operational power supply is capable.* The slewing rate is specified with the output fully loaded and measured as the output response to an input step function. As the exponential response to a step-input (such as a square wave, for example) is displayed on an oscilloscope, a slight increase in input amplitude will make rate limiting evident on the rising portion of the output waveform. (See FIG. 4-5.)

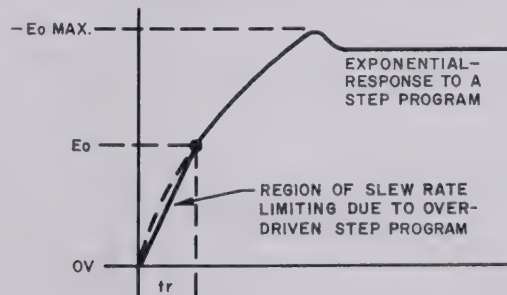


FIG. 4-5 DEFINITION OF MAXIMUM SLEWING RATE.

- 4-23 If a further increase of the driving signal amplitude does not produce a further change in the (E_o/t_r) slope of the displayed output response, the operational power supply is responding with the maximum slewing rate. The ratio E_o/t_r is measured over any convenient scale and the result is expressed in volts per microsecond.
- 4-24 If the input driving signal is a sinusoidal waveform instead of a step-function, the output waveform from the operational power supply is also a sinusoid. The maximum sine wave frequency which can produce the full output voltage (regardless of gain) is limited by the maximum slewing rate. The MAXIMUM SLEWING RATE and the FULL POWER SINE WAVE FREQUENCY ($f_{\max}$) are related by the equation:

$$\text{SLEWING RATE} = \pi f_{\max} E_{p-p}$$

where " E_{p-p} " represents the peak-to-peak output voltage of the operational power supply. The FULL POWER SINE WAVE FREQUENCY is specified for the frequency, where 5% total harmonic distortion occurs.

4-25 SIMPLIFIED DIAGRAM DISCUSSION (Refer to FIG. 4-6)

4-26 The POWER TRANSFORMER has five (5) secondary windings which are used to produce the a-c filament voltage for the SERIES PASS TUBE and the d-c operating potentials for the MAIN D-C SUPPLY, the SCREEN SUPPLY, the RETURN SUPPLY and the AMPLIFIER SUPPLY. The MAIN D-C SUPPLY is connected in series with the SERIES PASS TUBE, the CURRENT SENSING RESISTOR and the ($\pm$) OUTPUT terminals. The output level of the OPS is controlled by varying the series impedance of the POWER OUTPUT STAGE. The necessary drive to affect this control is provided by the DRIVER STAGE, which in turn receives its drive either from the VOLTAGE MODE or the CURRENT MODE AMPLIFIER.

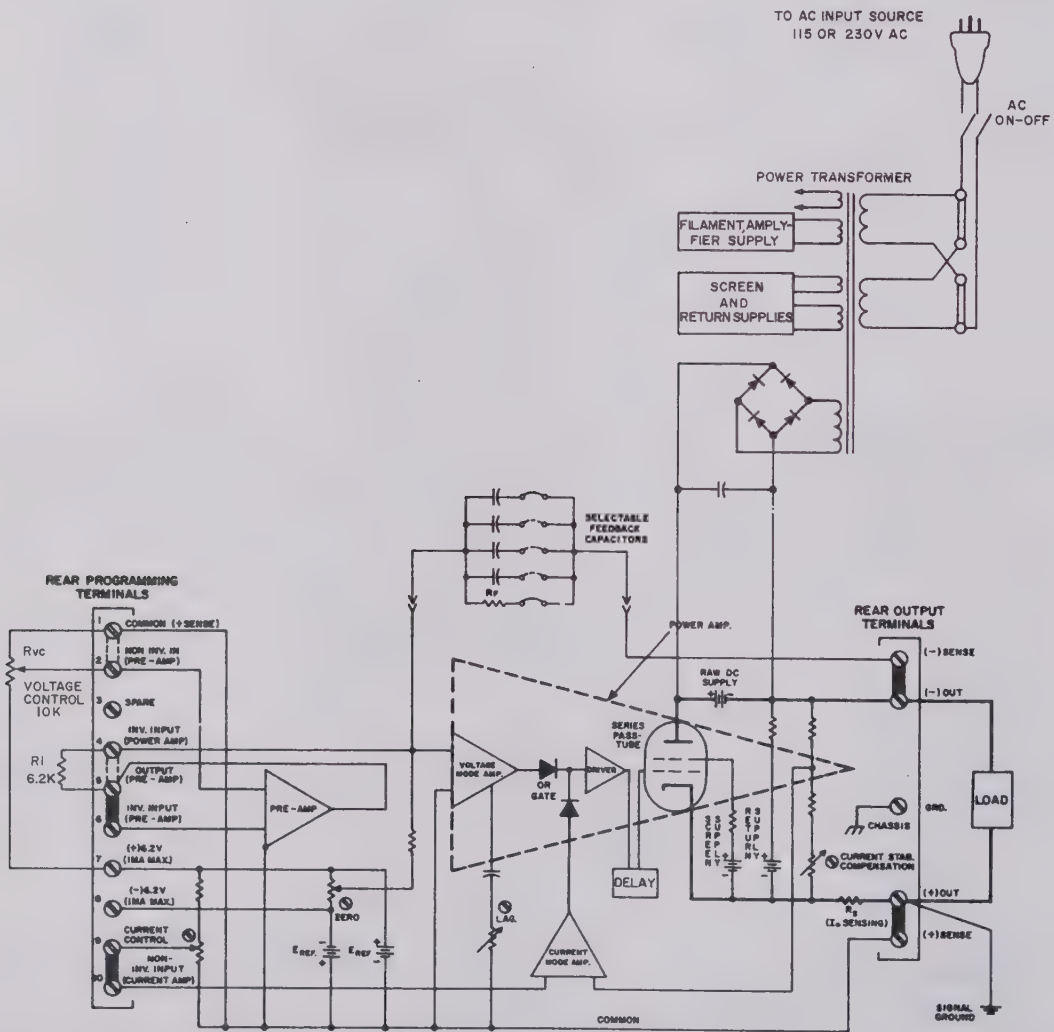


FIG. 4-6 SIMPLIFIED DIAGRAM, KEPCO OPS GROUP IX AS A D-C VOLTAGE OR CURRENT SOURCE.

- 4-27 If the OPS is used with the external voltage control resistor (R_{VC}), the internally provided feedback resistor (R_f) and the external input resistor (R_i) connected as shown in FIG. 4-6, it functions as a d-c source delivering stabilized output voltage or current to the load. The operating mode ("voltage" or "current") is determined by the load resistance and by the setting of the (external) VOLTAGE CONTROL and the (internal) OUTPUT CURRENT CONTROL. If, in FIG. 4-7, " E_o " (voltage) and " I_o " (current) represent the respective settings of the output controls, the "crossover" resistance (R_{LX}) is given by Ohm's Law:

$$R_{LX} = E_o / I_o.$$

- 4-28 Any load resistance, **smaller** than R_{LX} (as, for example, R_{LI} in FIG. 4-7) will transfer the OPS into the "Current Mode." With any load resistance **larger** than R_{LX} (as, for example, R_{LV} in FIG. 4-7), the OPS will operate in the "Voltage Mode."
- 4-29 Operating as a d-c source (as shown in FIG. 4-6), the OPS output voltage and current are constantly monitored and compared to the internal temperature-compensated REFERENCE SOURCE. The VOLTAGE MODE and CURRENT MODE AMPLIFIERS operate as "Error-Signal Amplifiers," and at balance, the settings of the output controls and the value of the load resistance establish a given operating point on the output characteristic, as described previously. A change in either output control setting, or an external influence on the set output quantities (change in load, variations in a-c source voltage) are interpreted by the OPS sensing circuits as "Error Signals." Depending on the prevailing operating mode of the OPS, the "error signal" is amplified by either the VOLTAGE MODE or the CURRENT MODE AMPLIFIER. The amplified error signal is presented to the OR-GATE, which only passes the most positive signal, so that only **one** of the amplifiers can be in control at any one time. Once the amplified error signal is passed by the OR-GATE, it becomes a "control signal" which, amplified by the DRIVER STAGE, is applied to the control grid of the SERIES PASS TUBE.⁽¹⁾ The SERIES PASS TUBE changes its series impedance in response to the control signal from the DRIVER STAGE. The control signal was derived from the "error signal" and is, therefore, proportional to the original output variation of the OPS. The resulting series impedance change in the SERIES PASS TUBE is, therefore, exactly inversely proportional to the original output variation, so that the OPS output is returned to the original value and thereby stabilized.
- 4-30 If the OPS is operated as a (unipolar) power amplifier, the INVERTING INPUT of the VOLTAGE MODE AMPLIFIER can be addressed directly, or via the output of the PREAMPLIFIER. Both operating methods are illustrated and described in Section III of this manual. (Refer for example to FIGS. 3-2 and 3-3.) The output of the OPS is "unipolar," varying in a single direction. The current control channel in this application is used as a "current limiter" by setting the CURRENT CONTROL to the maximum desired output current.
- 4-31 The current control channel may be remotely programmed, either by an external potentiometer, or by an external control voltage. Directions for remote control are given in Section II of this manual.

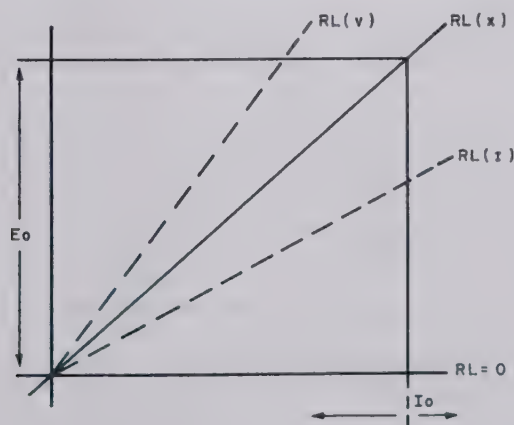


FIG. 4-7 "CROSSOVER" CHARACTERISTICS, OPS GROUP IX.

⁽¹⁾ At turn-on, the signal from the DRIVER STAGE is delayed for approximately 25 seconds by the DELAY CIRCUIT.

4-32 CIRCUIT DESCRIPTION (Refer to Main Schematic, FIG. 6-3)

4-33 For the purpose of analysis, the circuitry of the OPS Power Supply may be divided into several sections which are subsequently described below. Refer to the main schematic diagram, FIG. 6-3.

- a) A-C INPUT CIRCUIT. The a-c input power is introduced via the 3-wire line cord (detachable) with a 3-prong safety plug. The line cord ground wire (green), is directly connected to the metal chassis of the OPS, providing automatic grounding of the OPS case and chassis if a properly grounded a-c power outlet is used. The input fuse (F201) protects the OPS from overloads reflected into the a-c input circuitry. The POWER TRANSFORMER (T201) is equipped with dual primary windings, which are either operated in parallel (115V a-c nominal source voltage) or in series (230V a-c nominal source voltage). The OPS can be readily connected for either source voltage by a simple wire-jumper change on the primary of T201 (see Section II of this manual). Once the OPS is connected to the a-c source and the A-C POWER SWITCH (S201) is closed, the primary of the MAIN TRANSFORMER (T201) and the front panel A-C ON LIGHT are energized. The output voltage is delayed for approximately 25 seconds to permit the warm-up of the filament on the SERIES PASS TUBE. Any interruption of a-c source voltage will necessitate a new 25 second delay cycle.

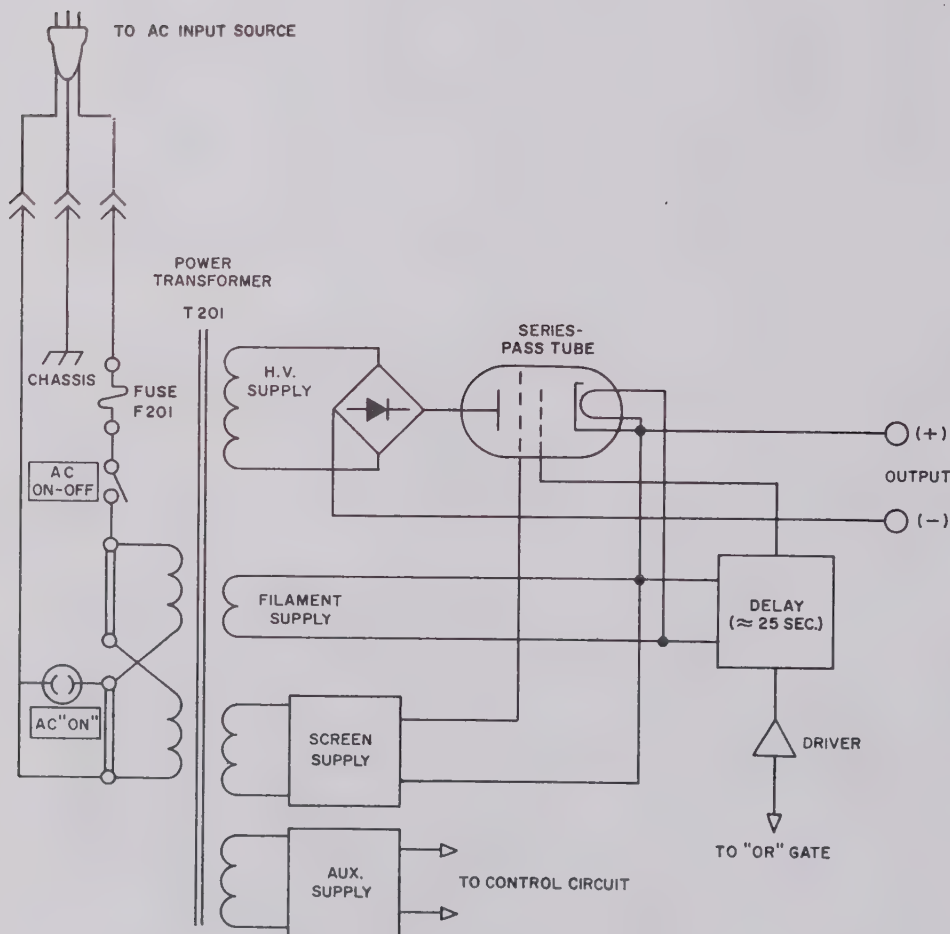


FIG. 4-8 SIMPLIFIED A-C INPUT CIRCUIT.

- b) MAIN D-C SUPPLY. The main d-c supply is derived from the secondary winding on the MAIN TRANSFORMER (T201). Rectified by the bridge rectifier (CR301 to CR304) and filtered by C201, the main d-c supply delivers the output power via the SERIES PASS TUBE (V301).
- c) SERIES PASS TUBE CIRCUIT. The SERIES PASS TUBE (V301) is electrically in series with the (unregulated) main d-c supply and the external load connected to the $\pm$ OUTPUT terminals on TB501. The output voltage at these terminals is being stabilized, regardless of variations in the unregulated d-c main supply or in external load conditions by the changing series conductance of the pass tube. The necessary control grid signal to affect the change in conductance is supplied by the DRIVER stage (Q2). The DRIVER stage, in turn, receives its control signals either from the VOLTAGE MODE (IC-3) or the CURRENT MODE AMPLIFIER (IC-2).
- d) VOLTAGE CONTROL CHANNEL. If the OPS is used as a stabilized d-c voltage source (as, for example, illustrated in FIG. 4-6), the VOLTAGE MODE AMPLIFIER (IC-3), serves as a comparator. The output voltage is sensed (via the feedback resistor R401)⁽¹⁾ at the $\pm$ SENSE terminals on TB501, and compared with a reference voltage at the inverting input (null junction) of IC-3. The reference potential may be applied (as a control voltage) to the inverting input of the VOLTAGE MODE AMPLIFIER via the output of the PREAMPLIFIER (IC-4, as shown in FIG. 4-6) or it may be applied directly. A condition of balance at the inverting input of the VOLTAGE MODE AMPLIFIER may be expressed by the equation:

$$\frac{E_o}{R_f} = \frac{E_i}{R_i} \quad , \text{ where: } \begin{array}{ll} E_o & = \text{Output Voltage} \\ E_i & = \text{Reference (Control) Voltage} \\ R_f & = \text{Built-in Feedback Resistor} \\ R_i & = \text{External Input Resistor} \end{array}$$

A change in any of the quantities in the balance equation will produce an "error signal" at the input of the VOLTAGE MODE AMPLIFIER. This amplifier is a high-gain integrated circuit "op-amp," which produces a control signal at the OR-GATE (CR11, CR12), thereby providing the base drive for driver transistor Q2. The drive from Q2 is phased and proportioned to influence the conductance of the SERIES PASS TUBE in such a way as to compensate exactly for the original change in the quantities of the balance equation.

- e) The inverting input of the VOLTAGE MODE AMPLIFIER (IC-3) is made available at the rear barrier-strip (TB502-4) and may be used for programming with voltage or current signals. The amplifier (IC-3) is stabilized by means of a lag network (C6, R28) which can be adjusted for optimum dynamic performance. The amplifier offsets can be compensated by the internal ZERO control (R22). The built-in feedback network R401⁽¹⁾ and C401-C404 is connected from the inverting input of IC-3 to the (-) SENSE terminal (TB501). The feedback resistor (R401)⁽¹⁾ can be disconnected by removing a jumper on the feedback assembly (A4). The feedback capacitors can be selected (by means of jumper links) for optimum dynamic response (see Section III of this manual).
- f) PREAMPLIFIER STAGE. An uncommitted preamplifier (IC-4) is provided which can be used for a variety of programming tasks. The output, as well as both inputs, are available at the rear barrier-strip (TB502-5, TB502-6, TB502-2).
- g) CURRENT CONTROL CHANNEL. The CURRENT MODE AMPLIFIER (IC-2) compares the voltage drop across the CURRENT SENSING RESISTOR (R17) to a reference or control potential, derived from the positive zener source (CR20) and established across the CURRENT CONTROL potentiometer (R25). Variations in output current flow (and consequent changes in the voltage drop across R17) or changes in the reference or control potential (as adjusted by means of the CURRENT CONTROL) result in an error signal across the differential input of the CURRENT MODE AMPLIFIER (IC-2). The amplified error signal from the IC-2 passes the GATE DIODE (CR12) as a control signal, taking control away from the VOLTAGE MODE AMPLIFIER (IC-3) and transferring the OPS into the "current mode" of operation. In the current mode of operation, the FEEDBACK RESISTOR (R401)⁽¹⁾ of the VOLTAGE CONTROL CHANNEL represents a shunt load by passing an "error current" in parallel with the external load.

A compensating circuit, consisting of a voltage divider (R501, R15, R16) is used in the OPS output circuit, providing a proportional compensating voltage, opposing the direction of the error current. A CURRENT STABILIZING COMPENSATION control (R16) is provided to adjust the compensation to exact proportionality with the error current, thus minimizing the output effects for load changes in the current mode of operation. Adjustment of the I_o COMP. control (R16) is indicated if the internal feedback resistor (R401)⁽¹⁾ is disconnected and an external feedback resistor of a different value is used.

⁽¹⁾R401, R402 on OPS 2000B.

- h) The purpose of the DELAY CIRCUIT (A6) is to provide a 25 second warm-up time for the filament of the SERIES PASS TUBS, before output voltage is available, and to prevent output voltage overshoot at turn-on and turn-off. The delay is achieved by means of the time constant of R601 and C603, in combination with the programmable unijunction transistor (Q601) and the SCR (CR604). As Q601 is turned "on", following the delay, it fires CR604 which in turn energizes the relay (K601), in series with the transistor (Q602). Until this time the SERIES PASS TUBE (V301) is held at cut-off by means of a large negative potential (via CR502 and R603). The normally closed contact of the relay (K602) maintains the voltage amplifier in "cut-off" condition. Once the relay energizes, the normally open contact closes, connecting the drive signal from the driver stage (Q2) to the control grid of V301 and the normally closed contact opens, driving the voltage amplifier from cut-off into normal controlling condition. The OPS turn-on is therefore achieved smoothly without any overshoot. At turn-off, the relay de-energizes immediately, since the transistor Q601 turns off fast, due to the very small time constant of its base drive resistor/capacitor network (R601,C601), removing the drive signal from the control grid of V301. The turn-on, turn-off sequence is repeated for each a-c power interruption.

NOTE:

A premature turn-on is possible (without overshoot) if the OPS is turned "off" prior to the normal 30-second time delay, and then turned "on" in the next 1- to 2-seconds. This premature turn-on should be avoided, however, in order to provide the proper warm-up time for the vacuum tubes.

j) AUXILIARY D-C VOLTAGE SOURCES

- 1) SCREEN SUPPLY. The d-c voltage for the screen grid of the SERIES PASS TUBE is derived from a secondary winding on the POWER TRANSFORMER (T201). The supply has full-wave rectification (CR305—CR306) and capacitive filtering (C303), and is connected from the cathode to the screen of the SERIES PASS TUBE (V301). The rectifiers are paralleled by noise filtering capacitors (C301—C302), while the main filter capacitor (C303) is provided with a "bleeder" resistor (R301).
- 2) RETURN SUPPLY. The return supply provides a small circulating current through the SERIES PASS TUBE to maintain feedback control at zero volts output. The supply is derived from a secondary winding on the POWER TRANSFORMER (T201). The full-wave rectifier consists of four (4) diodes (CR307—CR310) and the filter capacitor (C304). The supply is connected between the cathode of V301 and (via series resistors, R305—R307) the (-) output terminal.
- 3) AMPLIFIER POWER SUPPLY. Derived from the center-tapped secondary winding on the POWER TRANSFORMER, the raw d-c is provided by the full-wave rectifier (CR311, CR312) and capacitor-filtered (C305). The dual d-c voltage (± 13 volts) is stabilized by the differential amplifier (IC—1) with series transistor (Q1) and filtered by C2 and C3. The zener diodes at the output of the regulator circuit (CR3, CR4, CR6) provide additional stabilization and divide the supply into the required auxiliary potentials. The two reference potentials (± 6.2 V at 1 milliampere, available at front and rear terminals) are derived via series resistors (R23, R24) by means of temperature compensated zener diodes (CR17, CR20).
- 4) The FILAMENT SUPPLY is derived from a secondary winding on T201 and provides the heater voltage for the SERIES PASS TUBE (V301) and the operating potential for the DELAY CIRCUIT (A6).

SECTION V – MAINTENANCE

5-1 GENERAL

- 5-2 This section covers maintenance procedures, calibration, and test measurements of the Kepco OPS GROUP IX Power Supplies. Conservative rating of components and the noncongested layout should keep maintenance problems to a minimum. If trouble does develop, however, the easily removed wrap-around cover and the plug-in feature of the circuit boards provide exceptional accessibility to all components of the supply.

5-3 COVER REMOVAL

- 5-4 The wrap-around cover and the main printed circuit board (A1) may be easily removed by following the directions given in FIG. 5-1 below.

WARNING

THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:

- 1) *WHENEVER POSSIBLE, RETURN THIS INSTRUMENT TO THE FACTORY IF SERVICE IS NEEDED. IF EMERGENCY REPAIRS MUST BE PERFORMED, PROCEED WITH EXTREME CAUTION:*
- 2) *WHENEVER POSSIBLE, REMOVE THE A-C POWER COMPLETELY FROM THE OPS, BEFORE OPENING THE COVER.*
- 3) *IF THE OPS MUST BE OPERATED WITH OPEN COVER, MAKE CERTAIN OF THE FOLLOWING:*
 - A) *SET UP OPS IN A DRY, UNCLUTTERED AREA WHICH HAS AN INSULATED FLOOR.*
 - B) *GROUND THE CHASSIS AND THE POSITIVE OUTPUT SIDE OF THE OPS TO A GOOD A-C GROUND POINT. THIS WILL HELP GREATLY IN REDUCING THE SHOCK HAZARD, SINCE ALL AMPLIFIER AND AUXILIARY VOLTAGES ARE NOW CLOSE TO GROUND POTENTIAL.*
 - C) *TOUCH WIRING AND CIRCUITRY WITH INSULATED ROD OR TOOL ONLY. REMOVE A-C POWER BEFORE REMOVING ANY COMPONENT.*

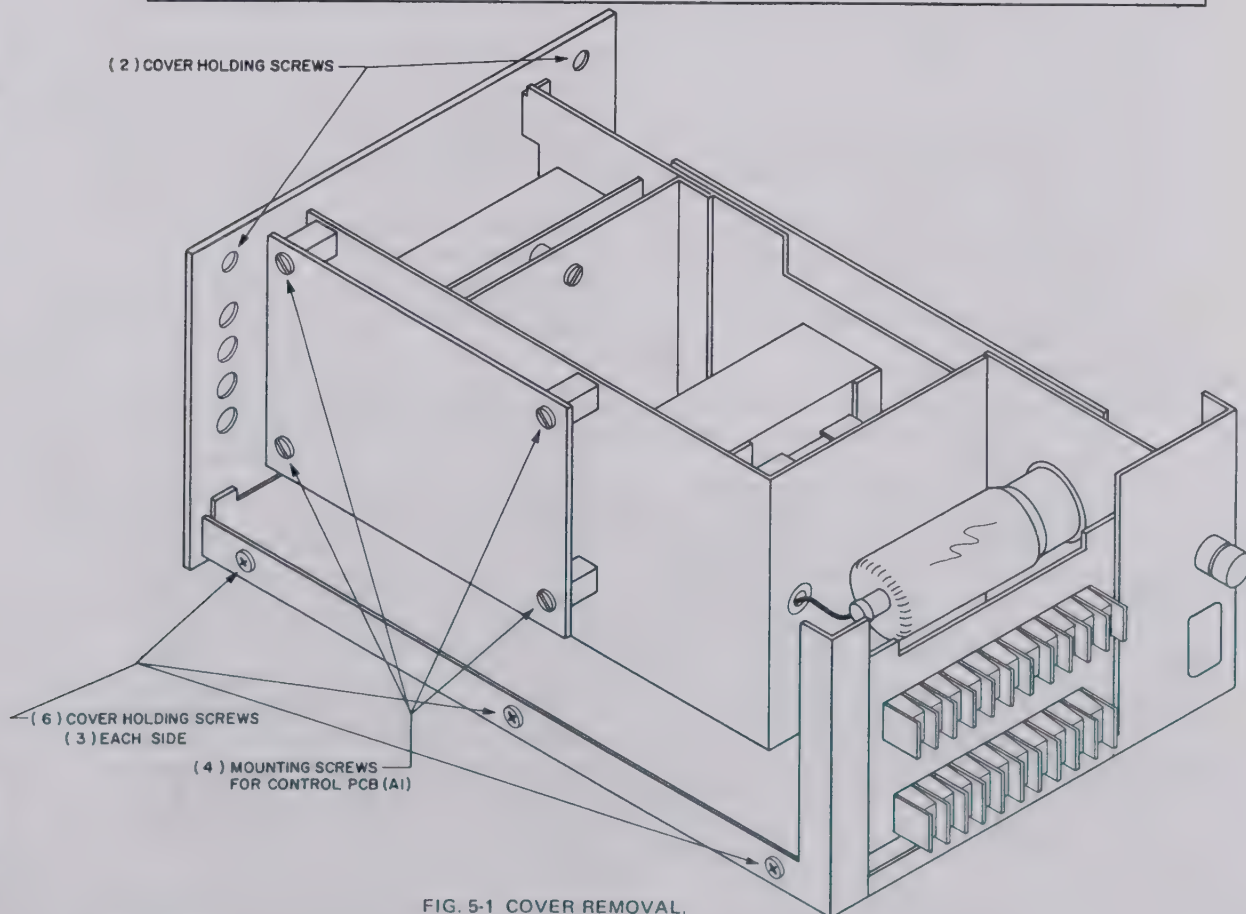


FIG. 5-1 COVER REMOVAL.

5-5 INTERNAL ADJUSTMENTS PROCEDURES

- 5-6 All available internal controls are located recessed from the front panel of the OPS. (See Section II, FIG. 2-1.) *The controls should be adjusted only with the insulated tool*, provided on the rear chassis of the OPS. (See Section II, FIG. 2-2.) Adjustment procedures for all controls have been provided throughout the text in Section III of this manual.

5-7 TROUBLE SHOOTING

- 5-8 Modern, high performance power supplies have reached a state of sophistication requiring a thorough understanding of the problems involved in repairing complex, solid-state circuitry. Servicing beyond simple parts replacement should consequently be attempted only by personnel thoroughly familiar with solid-state component techniques and with experience in closed-loop circuitry.

- 5-9 Trouble shooting charts showing resistance and voltage readings are of very limited usefulness with feedback amplifiers and are not included here. Instead, a detailed circuit description (Section IV), parts location diagrams, simplified functional schematics, and a main schematic with all significant voltage readings (Section VI) are presented in this manual.

- 5-10 The following basic steps in case of a power supply malfunction may be found helpful:

a) NO OUTPUT:

- 1) If power supply does not function at all, check obvious points first. Check a-c input source connections, a-c input source voltage and frequency. (Normally the power supply is connected for 115V a-c service.) Check fuse and replace if open.
- 2) Operate the power supply as a voltage source, as for example, shown in Section II, FIG. 2-4.
- 3) Check if the CURRENT CONTROL has been inadvertently misadjusted. Turn CURRENT CONTROL to approximately one-half its maximum *clockwise* position.
- 4) Remove OPS cover and check mating of the PC connectors with the PC boards. Check for correct jumper connections on the barrier-strip at the rear of the OPS. (See Section II, FIG. 2-4.)
- 5) Check indicated voltage readings on the main schematic, check transistors and vacuum tubes and start circuit analysis with the help of Section IV.

b) HIGH OUTPUT. Checks as listed in par. 5-10a (4 and 5) are also applicable for this condition. In addition, check the following:

- 1) Remove the driver transistor (Q2, located on the main amplifier Assembly A1, see Section VI, FIG. 6-3 for location). The output should now go slightly negative.
- 2) If it does, the series pass tubes and the high voltage d-c main supply sections are most likely not at fault.
- 3) Check driver transistor (Q2) and concentrate trouble shooting on the main amplifier board (A1). Check IC's and Q1, and look for burned components. Replace if necessary.
- 4) If output does not go to zero after Q2 is removed, check series pass tubes with a tube tester. Replace if defective. Check assembly A3 for burned or discolored components and replace if necessary.

c) POOR PERFORMANCE:

- 1) Excessive output variations are often due to incorrectly connected loads or faulty measurement techniques. Perform measurements only as directed in Section V and follow the connection diagrams.
- 2) High frequency oscillations at the output are often due to improperly adjusted lag networks (see Section III, par. 3-15) or to loads with large inductive or capacitive components and/or long load wires. (Maximum allowable capacitive loading = 1000 pF.) Tightly twisted load wires of sufficient diameter, kept as short as possible, are often the solution to the problem. *In extreme cases*, connect an additional feedback capacitor from (-) SENSE to TB502-4. NOTE: THE DYNAMIC SPECIFICATIONS ARE NOW NO LONGER APPLICABLE. THE EXTERNAL FEEDBACK CAPACITOR MUST BE RATED FOR THE MAXIMUM OPS OUTPUT VOLTAGE.
- 3) High ripple at the output or the load may be caused by ground loops or long load wires passing through magnetic fields. Grounding of one side of the output and careful lead dressing are often helpful. (Refer to Section III, par. 3-3c) for more signal grounding information.

- d) KEPCO Field Engineering Offices or the KEPCO Applications Engineering Department are always available for consultation or direct help in difficult service or applications problems.

5-11 OPERATIONAL POWER SUPPLY PERFORMANCE MEASUREMENTS

5-12 GENERAL. Measurements to verify the performance specifications are a frequent requirement of "Incoming Inspection" departments, a part of a routine maintenance program, or part of repair procedures. Some operational power supply measurements (OUTPUT IMPEDANCE, DRIFT, TEMPERATURE COEFFICIENT, etc.) require specialized test equipment and/or a controlled environment, and are therefore not described here. For information on these measurements, consult the Kepco Engineering Test Department. The measurements described in the following paragraphs, require only a minimum of equipment, and are generally sufficient to verify the most important d-c and dynamic performance specifications.

5-13 REQUIRED INSTRUMENTATION

- STABILIZED A-C INPUT SOURCE, with provisions for "stepping" the voltage over the specified a-c input range (105 to 125V or 210 to 250V). A variable AUTOTRANSFORMER is generally adequate if it can deliver the required a-c input current.
- RESISTOR LOAD, variable, capable of dissipating the full d-c output power of the unit under test and equipped with "on-off" and "shorting" switch (S1 in FIG. 5-2. Must be rated for the maximum OPS output voltage).
- D-C VOLTAGE MONITOR, digital or differential voltmeter, able to resolve at least 1 microvolt.

CAUTION: Large transient voltage spikes may appear across R_M as S1 is opened or closed. The precision voltmeter (M1) must, therefore, be protected by a surge-suppressor such as a metal-oxide varistor, Kepco Part No. 125-0012.

- OSCILLOSCOPE, vertical sensitivity at least 10 mV/div and with a minimum bandwidth of 10 megahertz.
- SQUARE-WAVE GENERATOR, with a variable output amplitude of 0–10 volts into 600 ohms and a rise time of approximately 0.1 microseconds. A "floating output," where the signal is available either in the positive or in the negative direction is desirable.

5-14 OUTPUT EFFECT MEASUREMENTS, CURRENT CONTROL CHANNEL. The output effects due to a-c source or d-c load variations in the **current mode** can be measured with the circuit shown in FIG. 5-2. These output effects ("SOURCE" AND "LOAD" EFFECT) are defined as **the amount of output current change, resulting from the specified variation in a-c source voltage, or from a change in load resistance**. The output effects can be expressed as an absolute change (ΔI_O), or as a percentage of the total output current (I_O):

$$\% \text{ OUTPUT EFFECT} = \frac{\Delta I_O}{I_O} (100\%) \quad (\text{Eq. 5-1}).$$

5-15 PROCEDURE (Refer to FIG. 5-2)

- To measure the SOURCE EFFECT, vary the a-c source voltage over the specified range (105 to 125V or 210 to 250V) and note the deviation ($\Delta V R_M$) on the voltmeter (M1 across R_M).
- To measure the LOAD EFFECT, close the load switch (S1) and note the deviation ($\Delta V R_M$) on the voltmeter (M1 across R_M).

NOTE: Before all measurements review Section III, pars. 3-18 to 3-23.

CAUTION: Large transient voltages may appear across R_M as S1 is opened or closed. M1 must, therefore, be protected by a surge-suppressor.

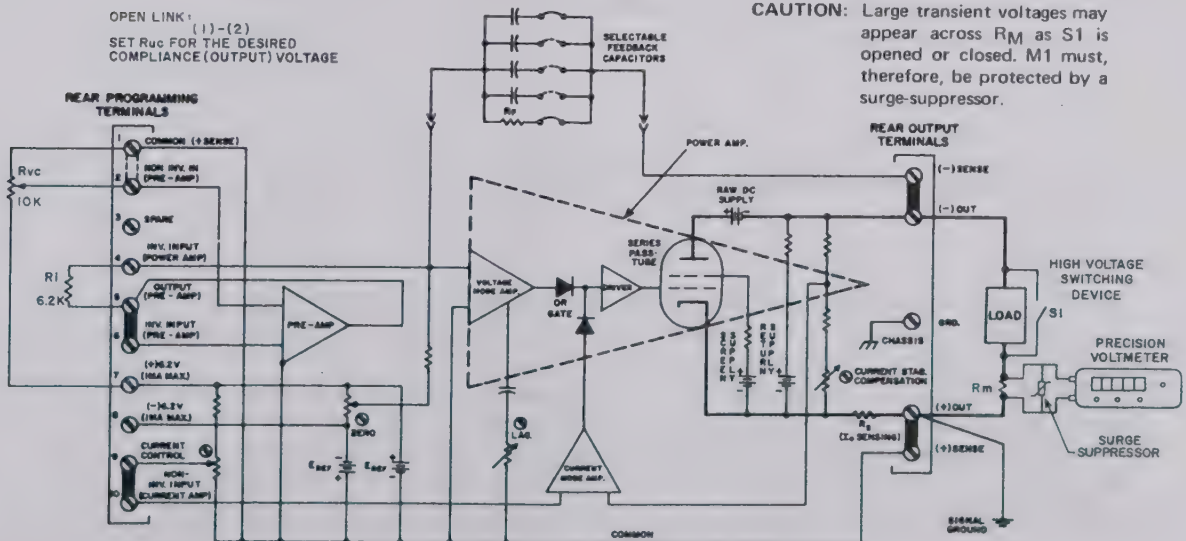


FIG. 5-2 OUTPUT EFFECT MEASUREMENTS, CURRENT CONTROL CHANNEL.

- 3) From the two previous measurements, the **output current change** is equal to:

$$\Delta I_O = \Delta V_{RM} / R_M.$$

Inserting the value for ΔI_O into equation 5-1, the **output effects** may be calculated in percentage form.

- 5-16 OFFSET MEASUREMENTS. The specified variations of the offset voltage and the offset current (ΔE_{iO} , ΔI_{iO}), can be verified (for a-c source changes) using the circuit shown in FIG. 5-3. These measurements provide a reliable check of the **d-c** performance of the OPS.

NOTE: Before all measurements review Section III, pars. 3-18 to 3-23.

CAUTION: Large transient voltages may appear across R_M as S1 is opened or closed. M1 must, therefore, be protected by a surge-suppressor.

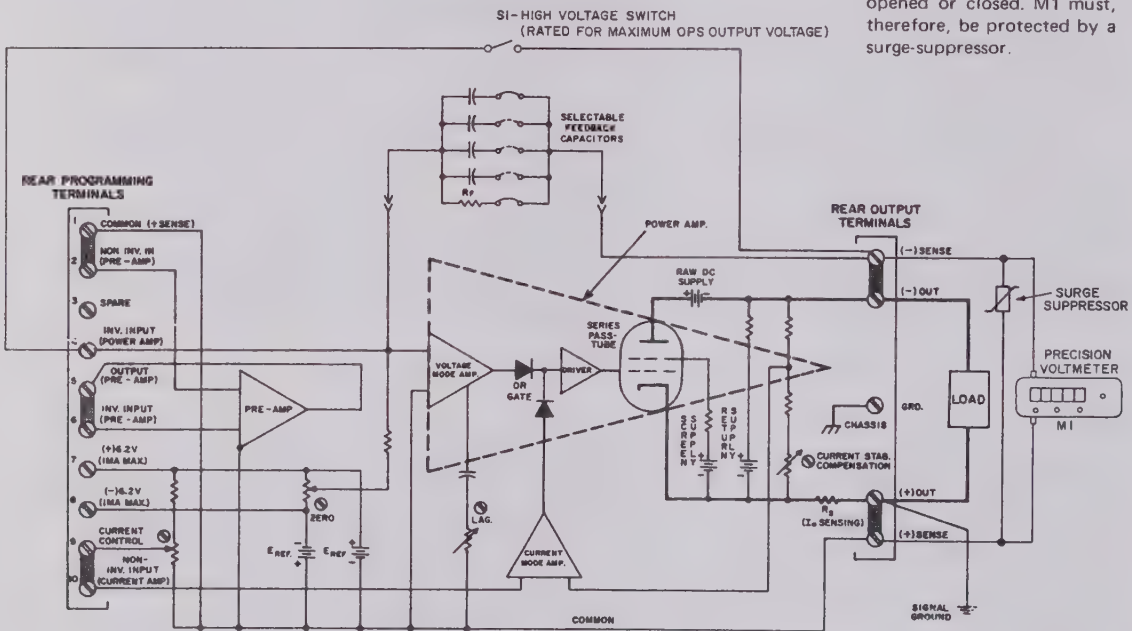


FIG. 5-3 OFFSET MEASUREMENTS (ΔE_{iO} , ΔI_{iO} FOR A-C SOURCE VARIATIONS) VOLTAGE CONTROL CHANNEL.

5-17 PROCEDURE (Refer to FIG. 5-3)

- 1) To measure ΔE_{iO} versus a-c source, **close** S1 and read E_{iO} (offset voltage) on the digital voltmeter at the output. Vary the a-c input source over the specified range (105 to 125V **or** 210 to 250V) and note the **variations** from the initial reading (ΔE_{iO}).
- 2) To measure ΔI_{iO} versus a-c source, **open** S1 and read E_O (output voltage). Since the offset current (I_{iO}) flows through the feedback resistor (R_f) it generates a measurable voltage (E_O) at the output (1 nanoampere of I_{iO} generates an output voltage of 1 millivolt across a feedback resistor of 1 M ohm for example. Vary the a-c input source over the specified range (105–125V **or** 210–250V) and note the **variation** from the initial reading (ΔI_{iO}).

5-18 DYNAMIC MEASUREMENTS. The specifications for the PROGRAMMING TIME CONSTANT and for the MAXIMUM SLEWING RATE can be verified using the circuit shown in FIG. 5-4.

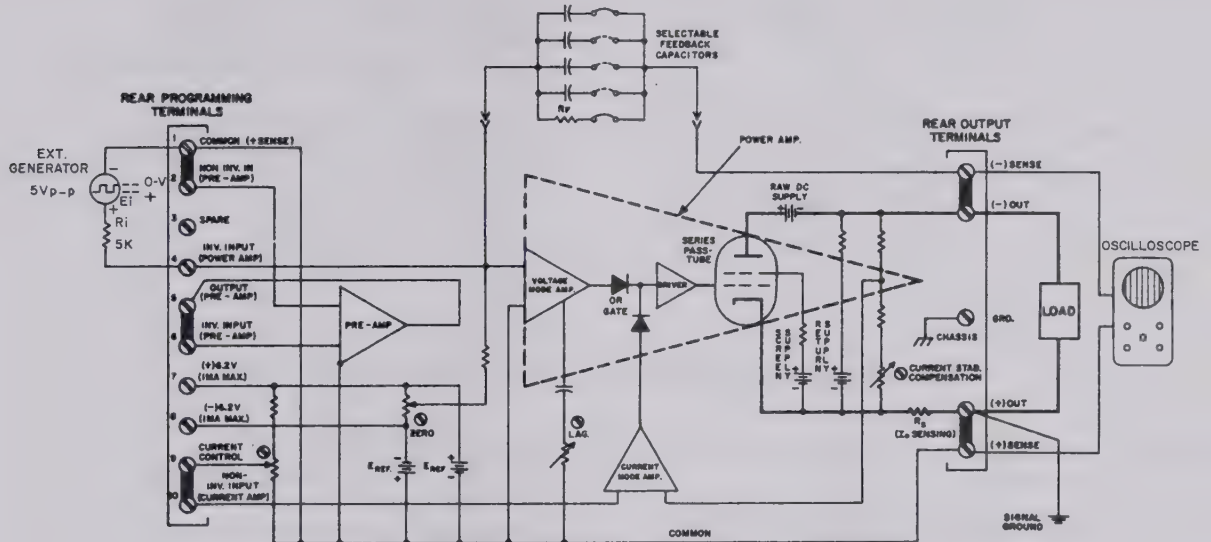


FIG. 5-4 DYNAMIC MEASUREMENTS, VOLTAGE CONTROL CHANNEL.

5-19 PROCEDURE (Refer to FIG. 5-4)

- 1) To measure the PROGRAMMING TIME CONSTANT, adjust the gain of the square-wave generator (E_i) until the output waveform (displayed on the oscilloscope) shows a peak amplitude equal to the maximum rated output voltage of the OPS model under test. (Refer to FIG. 5-5.) Review Section III, pars. 3-15 to 3-17 and optimize dynamic adjustments.

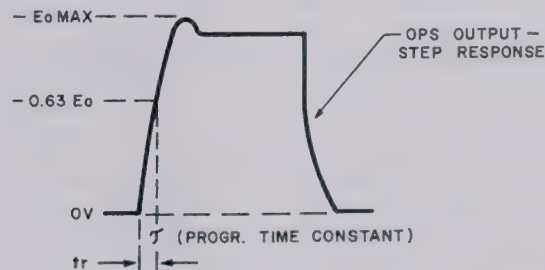


FIG. 5-5 OPS OUTPUT WAVEFORM FOR TIME CONSTANT MEASUREMENTS.

NOTE: Measure the rise time of the displayed waveform from zero (0V) to $-0.63 E_0$ = ONE TIME CONSTANT. This rise time (t_r) represents the PROGRAMMING TIME CONSTANT.

- 2) To measure the MAXIMUM SLEWING RATE, *increase* the gain of the square-wave generator at the input (E_i) until a *distinct breakpoint* in the up-slope of the output waveform becomes visible. The slope from "OV" to this breakpoint is the fastest rate of change of which the OPS under test is capable. Make certain that this true, by slightly increasing the gain of the square-wave generator. The slope (E_o/t_r) should not change. (Refer to FIG. 5-6.)

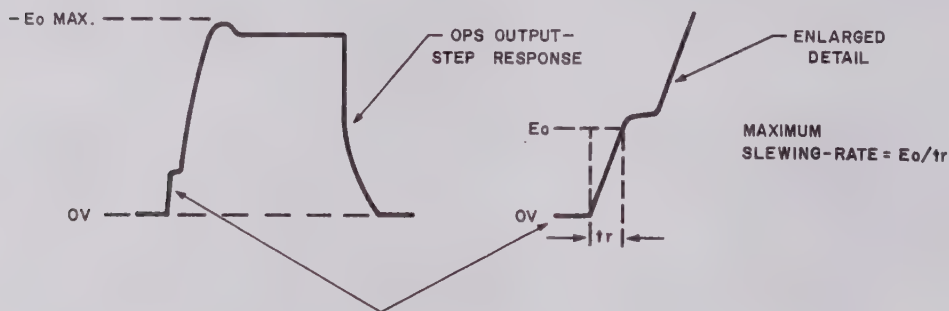


FIG. 5-6 OUTPUT WAVEFORM FOR SLEWING RATE MEASUREMENTS.

- NOTE:** 1) MEASURE " E_o " (ANY CONVENIENT VALUE ON THE SLOPE).
2) MEASURE " t_r ."
3) CALCULATE: MAXIMUM SLEWING RATE = $\Delta E_o/t_r$.

SECTION VI—ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 GENERAL

- 6-2 This section contains the main schematic, the parts location diagrams, and a list of all replaceable electrical parts. All components are listed in alpha-numerical order of their reference designations. Consult your Kepco Representative for replacement of parts not listed here.

6-3 ORDERING INFORMATION

- 6-4 To order a replacement part or to inquire about parts not listed in the parts list, address order or inquiry either to your authorized Kepco Sales Representative or to:

KEPCO, INC.
131-38 Sanford Avenue
Flushing, N.Y. 11352

- 6-5 Specify the following information for each part:
- a) Model and complete serial number of instrument.
 - b) Kepco part number.
 - c) Circuit reference designator.
 - d) Description.
- 6-6 To order a part not listed in the parts list, give a complete description and include its function and location.

NOTE: KEPKO DOES NOT STOCK OR SELL COMPLETE POWER SUPPLY SUBASSEMBLIES AS DESCRIBED HERE AND ELSEWHERE IN THIS INSTRUCTION MANUAL. SOME OF THE REASONS ARE LISTED BELOW:

- 1) Replacement of a complete subassembly is a comparatively rare necessity.
- 2) Kepco's subassemblies are readily serviceable, since most of them are of the "plug-in" type.
- 3) All active components are socket mounted, making replacement extremely easy.
- 4) The nature of a closed-loop power supply system requires that subassembly replacement is followed by careful measurement of the total power supply performance. In addition, depending on the function of the subassembly, extensive alignment may be required to restore power supply performance to specified values.

IF REPAIRS INVOLVING SUBASSEMBLY REPLACEMENTS ARE REQUIRED, PLEASE CONSULT YOUR LOCAL KEPKO REPRESENTATIVE OR THE KEPKO SALES ENGINEERING DEPARTMENT IN FLUSHING, NEW YORK, N.Y.

ABBREVIATIONS USED IN KEPKO PARTS LISTS

A) Reference Designators:

A	= Assembly	L	= Inductor
B	= Blower (Fan)	LC	= Light-Coupled Device
C	= Capacitor	M	= Meter
CB	= Circuit Breaker	P	= Plug
CR	= Diode	Q	= Transistor
DS	= Device, Signaling (Lamp)	R	= Resistor
F	= Fuse	S	= Switch
FX	= Fuse Holder	T	= Transformer
IC	= Integrated Circuit	TB	= Terminal Block
J	= Jack	V	= Vacuum Tube
K	= Relay	X	= Socket

B) Descriptive Abbreviations

A	= Ampere	MET	= Metal
a-c	= Alternating Current	n	= Nano (10 ⁻⁹)
AMP	= Amplifier	NC	= Normally Closed
AX	= Axial	NO	= Normally Open
CAP	= Capacitor	p	= Pico (10 ⁻¹²)
CER	= Ceramic	PC	= Printed Circuit
CT	= Center-Tap	POT	= Potentiometer
°C	= Degree Centigrade	PIV	= Peak Inverse Voltage
d-c	= Direct Current	p-p	= Peak to Peak
DPDT	= Double Pole, Double Throw	ppm	= Parts Per Million
DPST	= Double Pole, Single Throw	PWR	= Power
ELECT	= Electrolytic	RAD	= Radial
F	= Farad	RECT	= Rectifier
FILM	= Polyester Film	RECY	= Recovery
FLAM	= Flammable	REG	= Regulated
FP	= Flame-Proof	RES	= Resistor
°F	= Degree Fahrenheit	RMS	= Root Mean Square
FXD	= Fixed	Si	= Silicon
Ge	= Germanium	S-End	= Single Ended
H	= Henry	SPDT	= Single Pole, Double Throw
Hz	= Hertz	SPST	= Single Pole, Single Throw
IC	= Integrated Circuit	Stud Mt	= Stud Mounted
K	= Kilo (10 ³)	TAN	= Tantalum
m	= Milli (10 ⁻³)	TSTR	= Transistor
M	= Mega (10 ⁶)	μ	= Micro (μ) (10 ⁻⁶)
MFR	= Manufacturer	V	= Volt
		W	= Watt
		WW	= Wire Wound



KEPCO. REPLACEMENT PARTS LIST

MODEL OPS 2000B, CONTROL CIRCUIT ASSEMBLY (A1)

Code 6-2575

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C1,6	2	Capacitor,Mylar,Axial Leads 0.02 μ F, 200V, $\pm$ 10%	Sprague Type 192P	117 0377	1
C2	1	Capacitor,Elect.,Axial Leads 100 μ F, 15V, $\pm$ 20%	General Electric Type 76F	117-0523	1
C3	1	Capacitor,Elect.,Axial Leads 100 μ F, 75V, +100% - 10%	General Electric Type 43F	117-0514	1
C4,7,8	3	Capacitor,Ceramic,Disc. 100 pF, 500V, $\pm$ 10%	Radio Materials Type JK	117-0754	1
C5	1	Capacitor,Mylar,Axial Leads 0.05 μ F, 200V, $\pm$ 20%	TRW Type 663F	117-0315	1
C9	1	Capacitor,Ceramic,Disc. 0.01 μ F, 500V, $\pm$ 20%	Radio Materials Type B	117-0084	1
C10	1	Capacitor,Mylar,Met.,Ax. Leads 0.001 μ F, 200V, $\pm$ 10%	Sprague 192P	117-0570	1
CR2,5,9,11, 12,13,14,15, 16,18,19	11	Diode Switching 75V PIV, 400 mW	American Power Devices 1N4148	124-0437	2
CR3,4,6	3	Diode,Zener 6.5V, $\pm$ 5%	International Rectifier 121-0028	121-0028	1
CR7,8	2	Signal Diode,Dual $V_f = 1.3V$ min at $I_f = 10$ mA	American Power Devices Type APD 203	124-0435	1
CR10	1	Diode,Rectifier 4000 PIV, 150 mA	Semicon HV-40	124-0163	1
CR17,20	2	Diode,Zener,Reference 6.2V, $\pm$ 5%	Motorola 121-0041	121-0041	1
CR21	1	Diode,Zener,Axial Leads 38V $\pm$ 5%, 1 W	International Rectifier 1N4754A	121-0061	1
IC1,2,4	3	I.C. Operational Amplifier (741C)	Raytheon RC741DN	250-0025	1
IC3	1	I.C. Operational Amplifier 8 Pin DIP	Texas Instruments SN72307P	250-0039	1
Q1	1	Transistor,Silicon,NPN Small Signal	Transitron 2N3053	119-0059	1
Q2	1	Transistor,Silicon,PNP Small Signal	Fairchild 2N4355	119-0076	1
R1,24	2	Resistor,Fixed,Precision,M.F. 750 ohm, 1/4 W, 1%	Dale MFF-1/4	115-1803	1
R2,3	2	Resistor,Fixed,Precision,M.F. 10 k ohm, 1/8 W, 1%	Dale MFF-1/8	115-2174	1
R4	1	Resistor,Fixed,Molded 2 k ohm, 2 W, 5%	Allen Bradley HB2025	115-0074	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



KEPCO. REPLACEMENT PARTS LIST

MODEL OPS 2000B, CONTROL CIRCUIT ASSEMBLY (A1)

Code 1-2574

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R5	1	Resistor,Fixed,Axial Leads,W.W. 1 k ohm, 3 W, 5%	Tepro TS-3C	115-1302	1
R6,18,20	3	Resistor,Fixed,Precision,M.F. 1 k ohm, 1/4 W, 1%	Dale MFF-1/4	115-1822	1
R7,12,13	3	Resistor,Fixed,Molded 1 k ohm, 1/4 W, 10%	IRC GBT-1/4	115-2238	1
R9	1	Resistor,Fixed,Molded 68 k ohm, 1/2 W, 5%	Allen Bradley EB6805	115-0273	1
R10	1	Resistor,Fixed,Molded 47 k ohm, 1/4 W, 10%	IRC GBT-1/4	115-2237	1
R14,29	2	Resistor,Fixed,Molded 500 ohm, 1 W, 3%	Tepro TS-1W	115-1248	1
R15	1	Resistor,Fixed,Precision 909 ohm, 1/4 W, 1%	IRC Type CES	115-1976	1
R16	1	Resistor,Variable,Cermet 500 ohm, 3/4 W, 30%	Bourns Type 3059Y	115-2063	1
R17	1	Res.,Fixed,Axial Leads,W.W. 100 ohm, 3 W, 5%	Tepro TS-3C	115-0471	1
R21	1	Resistor,Fixed,Precision 2.67 M ohm, 1/2 W, 1%	Dale MFF-1/2	115-2313	1
R22	1	Resistor,Variable,W.W. 20 k ohm, 1 W, 5%	TRW Type 400-20	115-2363	1
R23	1	Resistor,Fixed,Precision,M.F. 732 ohm, 1/2 W, 1%	Dale MFF-1/2	115-2081	1
R25	1	Resistor,Variable,Cermet 2 k ohm, 3/4 W, 20%	Bourns Type 3059Y	115-2032	1
R26	1	Resistor,Fixed,Precision,M.F. 7.32 k ohm, 1/8 W, 1%	Dale MFF-1/8	115-2335	1
R28	1	Resistor,Variable,Cermet 1 k ohm, 3/4 W, 20%	Bourns Type 3059Y	115-2035	1
R11,30	2	Resistor,Fixed,Molded 2 k ohm, 1/2 W, 5%	Allen Bradley EB2025	115-0520	1
RV1	1	Varistor,Metal,Oxide	General Electric V130LA1	125-0011	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



KEPCO. REPLACEMENT PARTS LIST

MODEL OPS 2000B, MAIN CHASSIS ASSEMBLY (A2)

Code 7-1775

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
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FRONT PANEL ASSEMBLY CONTAINS:

DS101	1	Pilot Light Assembly	Industrial Devices 1040A75	152-0070	1
S101	1	Switch, SPST	Stackpole RS47FB	127-0230	0
RC101	1	RC Network 100 ohm, 1/2 W, 10% in series with 0.1 mF, 400V	Sprague 288P10404B101	245-0003	1
C201	1	Capacitor, Paper, Can, Dual 0.25 + 0.05 μ F, $\pm$ 10%, 4 kV	General Electric Type 28F	117-0380	1
F201	1	Fuse, Slo Blo 0.8A	Bussmann MDL-8/10	141-0027	5
R201	1	Resistor, Power, Axial 7.5 M ohm, 2 W, 5%	IRC Type MVX-2	115-1317	1
T201	1	Transformer	Kepco Magnetics 100-2038	100-2038	1
L201	1	Choke	Miller #6302	176-0052	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



KEPCO. REPLACEMENT PARTS LIST

MODEL OPS 2000B, AUXILIARY ASSEMBLY (A3)

Code 1-2574

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C301,302	2	Capacitor,Mylar,Axial Leads 0.01 μ F, 400V, $\pm$ 20%	Sprague Type 192P	117-0361	:
C303	1	Capacitor,Elect.,Axial Leads 60 μ F, 175V, +50% - 10%	General Electric Type 43F	117-0466	1
C304	1	Capacitor,Mylar,Axial Leads 0.25 μ F, 1 kV, $\pm$ 20%	Good All Type 633UW	117-0066	1
C305	1	Capacitor,Elect.,Axial Leads 80 μ F, 120V, +100% - 10%	General Electric Type 43F	117-0427	1
C306	1	Capacitor,Ceramic,Disc. 680 pF, 6 kV, $\pm$ 20%	Centralab DD60-681	117-0721	1
CR301,302, 303,304	4	Diode,Rectifier,Axial Leads 4 kV PIV, 150 mA	Semicon HV-40	124-0163	2
CR305,306, 311,312	4	Rectifier,Silicon,Axial Leads 400V PIV, 1A	Semicon SI-4	124-0028	2
CR307,308, 309,310	4	Rectifier,Silicon,Axial Leads 2 kV PIV, 0.5A	Semicon HV-20	124-0299	2
R301	1	Resistor,Fixed,Molded 150 k ohm, 1/2 W, 5%	Allen Bradley EB1545	115-0243	1
R302	1	Resistor,Fixed,Molded 3.9 k ohm, 1/2 W, 10%	Allen Bradley EB3921	115-0921	1
R303	1	Resistor,Fixed,Molded 1 k ohm, 1/2 W, 10%	Allen Bradley EB1021	115-0547	1
R305,306,307	3	Resistor,Fixed,Power,Axial 250 k ohm, 10 W, 3%	Tepro TS-10W	115-1254	1
R308	1	Resistor,Fixed,Molded 100 k ohm, 2 W, 10%	Allen Bradley HB1041	115-0197	1
V301	1	Vacuum Tube	General Electric 8068	126-0096	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



KEPCO. REPLACEMENT PARTS LIST

MODEL OPS 2000B, FEEDBACK ASSEMBLY (A4)

Code 1-2574

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C401	1	Capacitor,Ceramic,Disc. 100 pF, 3 kV, $\pm 20\%$	Radio Materials Type Z5F	117-0058	1
C402	1	Capacitor,Ceramic,Disc. 200 pF, 6 kV $\pm 20\%$	Radio Materials Type Z5F	117-0075	1
C403	1	Capacitor,Ceramic,Disc. 500 pF, 2 kV $\pm 20\%$	Radio Materials Type Z6F	117-0584	1
C404	1	Capacitor,Ceramic,Disc. 1000 pF, 3 kV $\pm 20\%$	Radio Materials Type Z5F	117-0583	1
R401,402	2	Resistor,Fixed,Precision,W.W. 1 Megohm, 2 W, 1%	Kelvin Associates Type RB-59	115-2186	1

MODEL OPS 2000B, REAR TERMINAL ASSEMBLY (A5)

CR501	1	Diode,Rectifier 4 kV, PIV, 150 mA	Semicon HV-40	124-0163	1
R501	1	Resistor,Fixed,Power,Axial 20 M ohm, 1 W, 5%	Dale DC-1-3KV	115-2147	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



KEPCO. REPLACEMENT PARTS LIST

OPS 2000B, DELAY ASSEMBLY (A6)

Code 9-2377

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C601	1	Cap., Fxd, Tantalum, Ax. Leads 1uF, +50, -15%, 50V	Sprague Type 162D	117-0815	1
C602	1	Cap., Fxd, Elect., Ax. Leads 290uF, +75, -10%, 12V	Sangamo Type 556	117-0647	1
C603	1	Cap., Fxd, Elect., Ax. Leads 150uF, +75, -10%, 15V	Sprague Type DSM	117-0677	1
C604	1	Cap., Fxd, Ceramic Disc 0.005uF, 20%, 500V	Radio Materials Corp. Type SM	117-0061	1
C605	1	Cap., Fxd, Elect., Ax. Leads 10uF, +50, -10%, 100V	Sangamo Type 556	117-0439	1
C606	1	Cap., Fxd, Film, Ax. Leads 0.001uF, 10%, 200V	Sprague Type 192P	117-0570	1
CR601	1	Rect. Bridge, Rad. Leads 200V (PIV), 1A	General Instruments Type W-02	124-0346	1
CR602,603, 605	3	Diode, Rectifier, Ax. Leads 100V (PIV), 1A	Semicon SI-1	124-0133	1
CR604	1	Thyristor, SCR 75V (PIV), 8A	Motorola 2N4441	124-0349	1
CR606	1	Diode, Rect., Ax. Leads 400V (PIV), 1A	Semicon Inc. SI-4	124-0028	1
K601	1	Relay, Dry-Reed 1A-1B, 6V-75mA Coil	Potter And Brumfield JRD50DO-1	140-0093	1
Q601	1	TRST., Si, NPN, PUT TO-92	General Electric 2N6027	119-0111	1
Q602	1	TRST., Si, PNP Small Signal, TO-18	Fairchild 2N4355	119-0076	1
R601	1	Res., Fxd, Met. Film 150K ohm, 1%, 1/8W	Dale MFF-1/8	115-2597	1
R602	1	Res., Fxd, Molded 47 ohm, 10%, 1/4W	TRW Type GBT-1/4	115-2273	1
R603	1	Res., Fxd, Molded 10K ohm, 10%, 1/4W	TRW Type GBT-1/4	115-2211	1
R604	1	Res., Fxd, Molded 120 ohm, 10%, 1/4W	TRW Type GBT-1/4	115-2232	1
R605	1	Res., Fxd, Met. Film 18.2K ohm, 1%, 1/8W	Dale Type MFF-1/8	115-2275	1
R606	1	Res., Fxd, Met. Film 30.1K ohm, 1%, 1/8W	Dale Type MFF-1/8	115-2541	1
R607	1	Res., Fxd, Met. Film 499K ohm, 1%, 1/8W	Dale Type MFF-1/8	115-2309	1
R608	1	Res., Fxd, Molded 15K ohm, 10%, 1/4W	TRW Type GBT-1/4	115-2497	1
R609	1	Res., Fxd, Molded 5.6K ohm, 10%, 1/4W	TRW Type GBT-1/4	115-2491	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES

KEPCO, INC

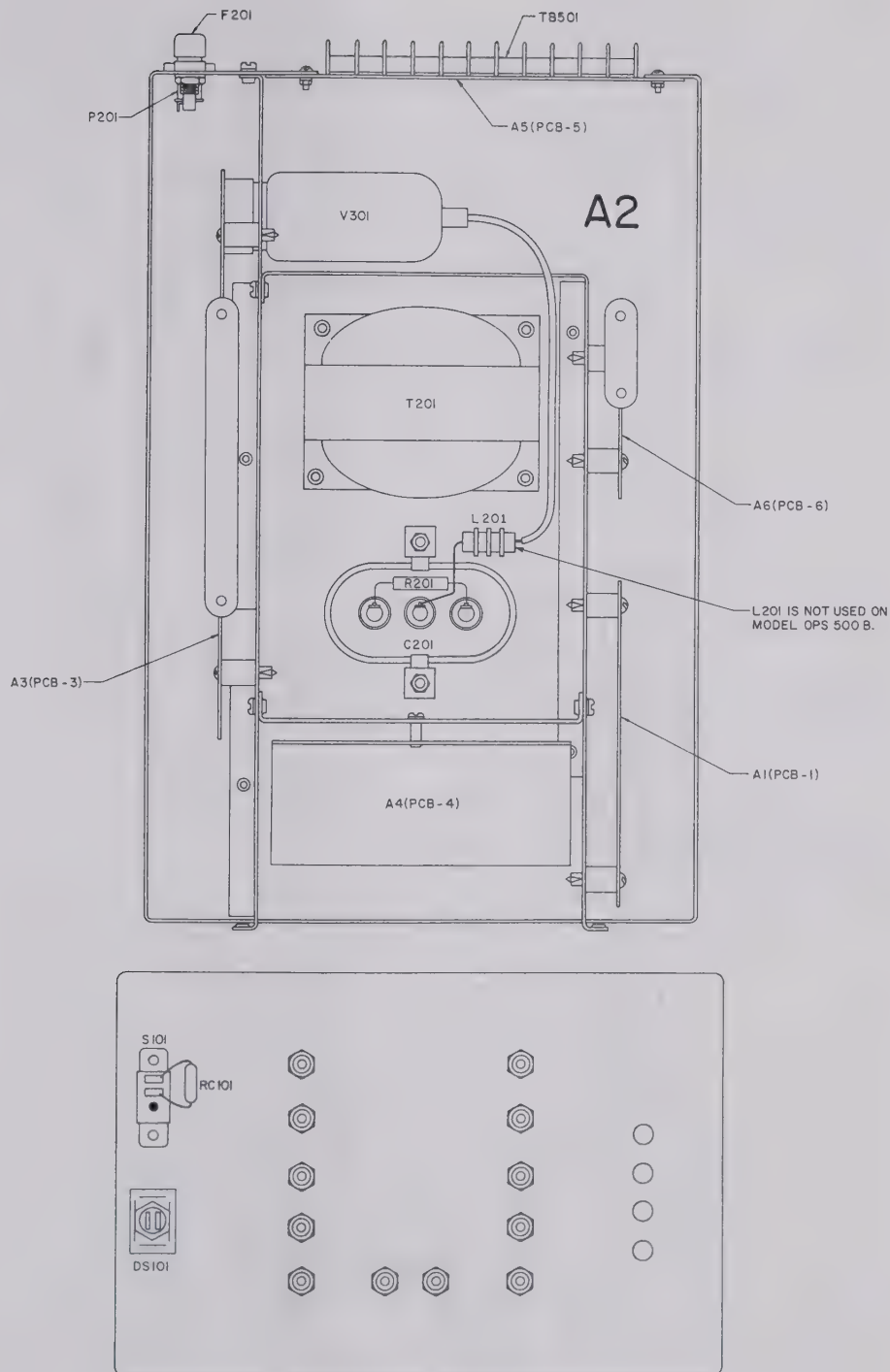


FIG. 6-1 COMPONENT LOCATION, MAIN CHASSIS ASSEMBLY (A2).

NOTE: C10 NOT USE IN MODEL OPS500B

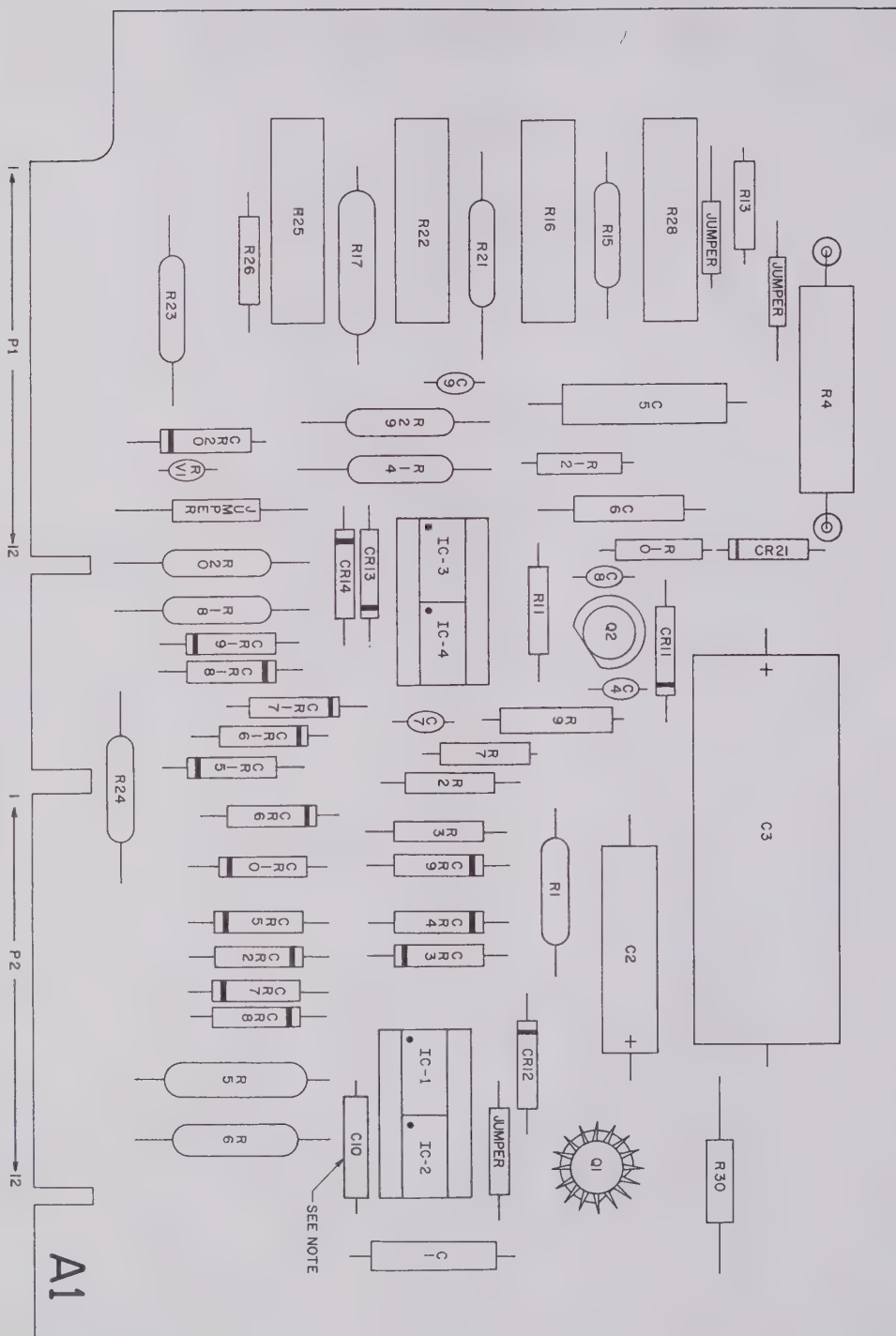
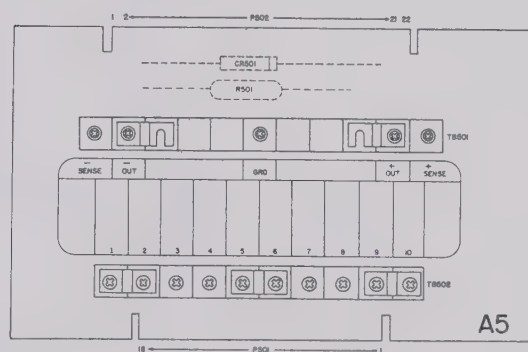
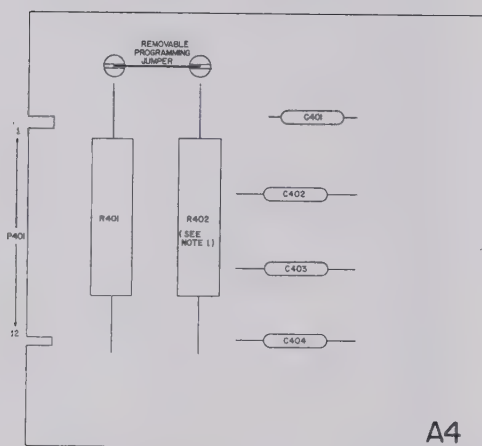
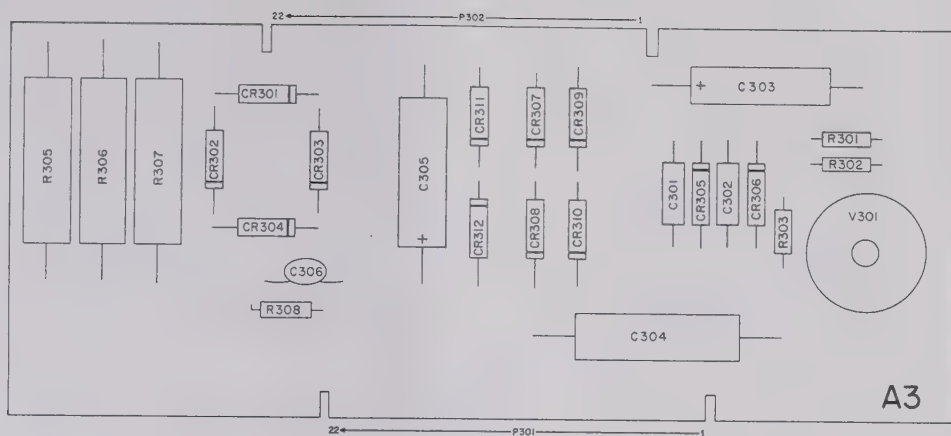


FIG. 6-2 COMPONENT LOCATION, CONTROL ASSEMBLY (A1).



NOTES
1. MODELS OP5500B & OP5000B HAVE A JUMPER
IN PLACE OF R402

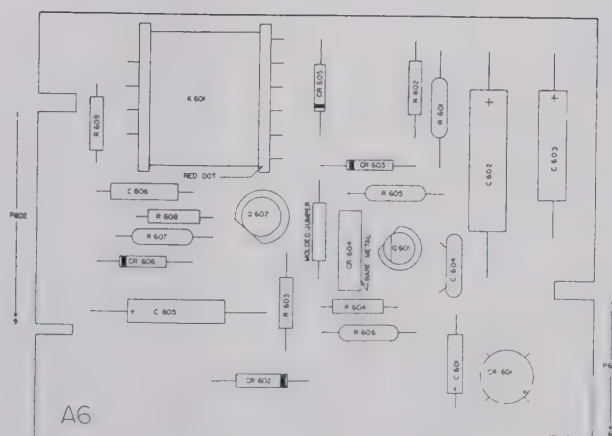
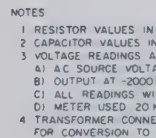


FIG. 6-3 COMPONENT LOCATION, AUXILIARY ASSEMBLIES (A3, A4, A5, A6).



FM 13185/9-2377

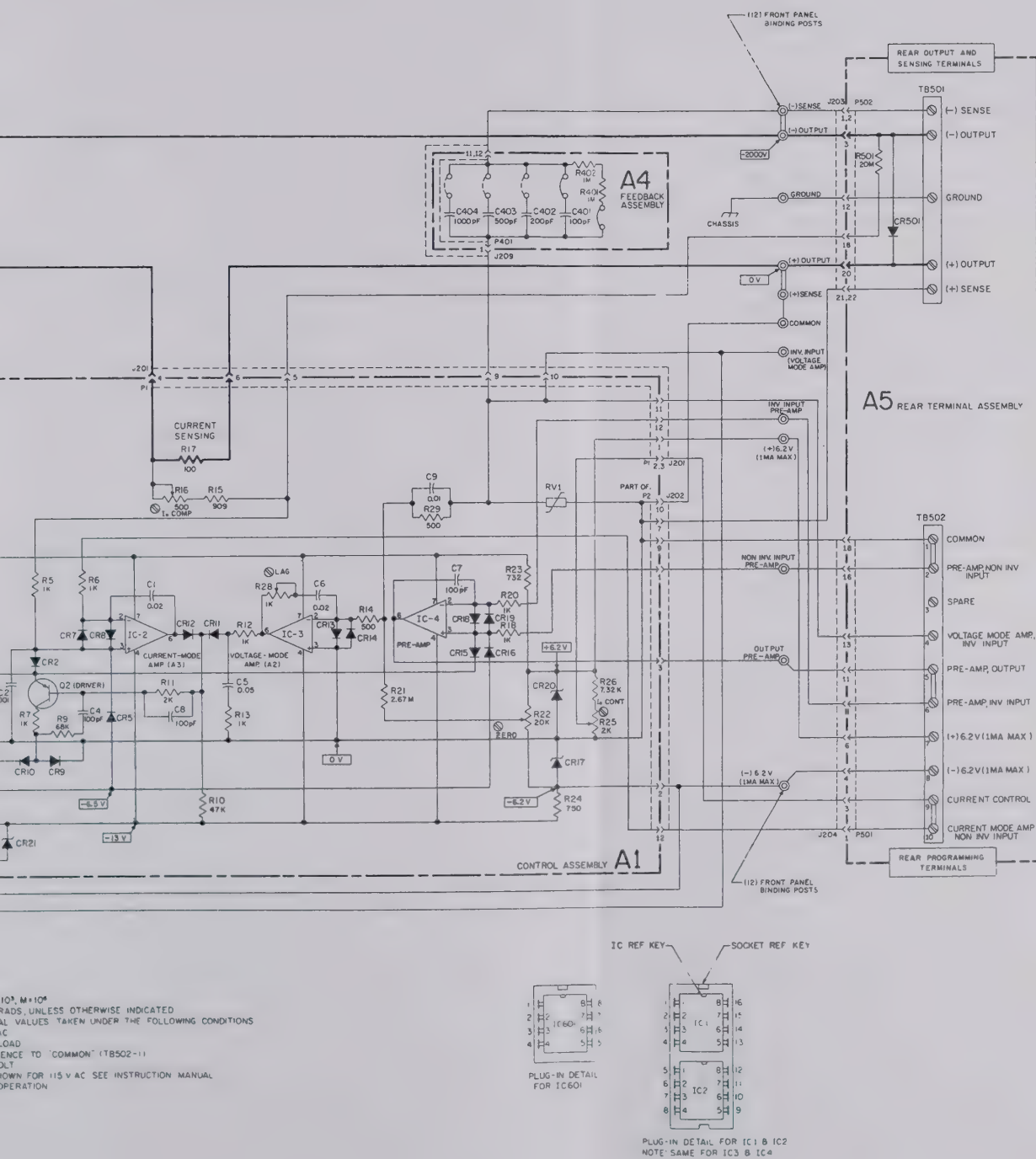


FIG. 6-4 MAIN SCHEMATIC, MODEL OPS 2000B.

Please note the following corrections to the Manual Material as indicated:

PARTS LIST AND SCHEMATIC DIAGRAM:

1. CHANGE:	R2	Resistor, Fixed, Prec. M.F.	10K ohm, 1/8W, 1%	Kepco #115-2174
TO:	R2	Resistor, Fixed, Prec. M.F.	8.06K ohm, 1/8W, 1%	Kepco #115-2445
2. CHANGE:	R501	Resistor, Fixed, Composition Film	20M ohm, 1W, 5%	Kepco #115-2147
TO:	R501	Resistor, Fixed, Thick Film	20M ohm, 1W, 2%	Kepco #115-2618
3. CHANGE:	C201	Capacitor, Dual, Paper, Can	.25/.05uf, 4KV, 10%	Kepco #117-0380
TO:	C201	Capacitor, Poly/Paper, Can	.25/.05uf, 4KV, 10%	Kepco #117-0922
4. CHANGE:	R603	Resistor, Fixed, Molded	10K ohm, 1/4W, 10%	Kepco #115-2211
TO:	R603	Resistor, Fixed, Molded	1.8K ohm, 1/4W, 10%	Kepco #115-2470
5. ADD:	R32	Resistor, Fixed, Molded	220 ohm, 1/4W, 1%	Kepco #115-2227
6. ADD:	C11	Capacitor, Ceramic, Disc.	0.005uf, 500V, 20%	Kepco #117-0061

Note: "C11 and R32 have been added to Assembly A1. R32 is connected in series with pin 7 of IC-1 to the positive side of the auxiliary supply. C11 is connected from pin 7 of IC-1 to common (ov)".

7. CHANGE:	IC1	IC.OP.AMP.	8 Pin Dip (741C)	Kepco #250-0025
TO:	IC1	IC.OP.AMP.	8 Pin Dip	Kepco #250-0158
8. CHANGE:	R22	Resistor, Variable, W.W.	20K ohm, 10%, 1W	Kepco #115-2363
TO:	R22	Resistor, Variable, Cermet	20K ohm, 20%, 1W	Kepco #115-1961
9. CHANGE:		Pilot Light		Kepco #152-0070
TO:		Pilot Light		Kepco #152-0089

OPS 2000B/02-1176/r6	C3519	OPS 2000B-11-30-90/r15	C6252
OPS 2000B/02-2376/r6	C3550		
OPS 2000B/09-2377/r7	C3772		
OPS 2000B/06-2178/r8	C3988		
OPS 2000B/02-1479/r9	C4223		
OPS 2000B/11-2680/r10	C4728		
OPS 2000B/12-0981/r10	BMC		
OPS 2000B/02-0581/r11	C4749		
OPS 2000B/09-2586/r12	C5730		
OPS 2000B-09-2686/r13	C5731		
OPS 2000B/12-1288/r14	C6087		

